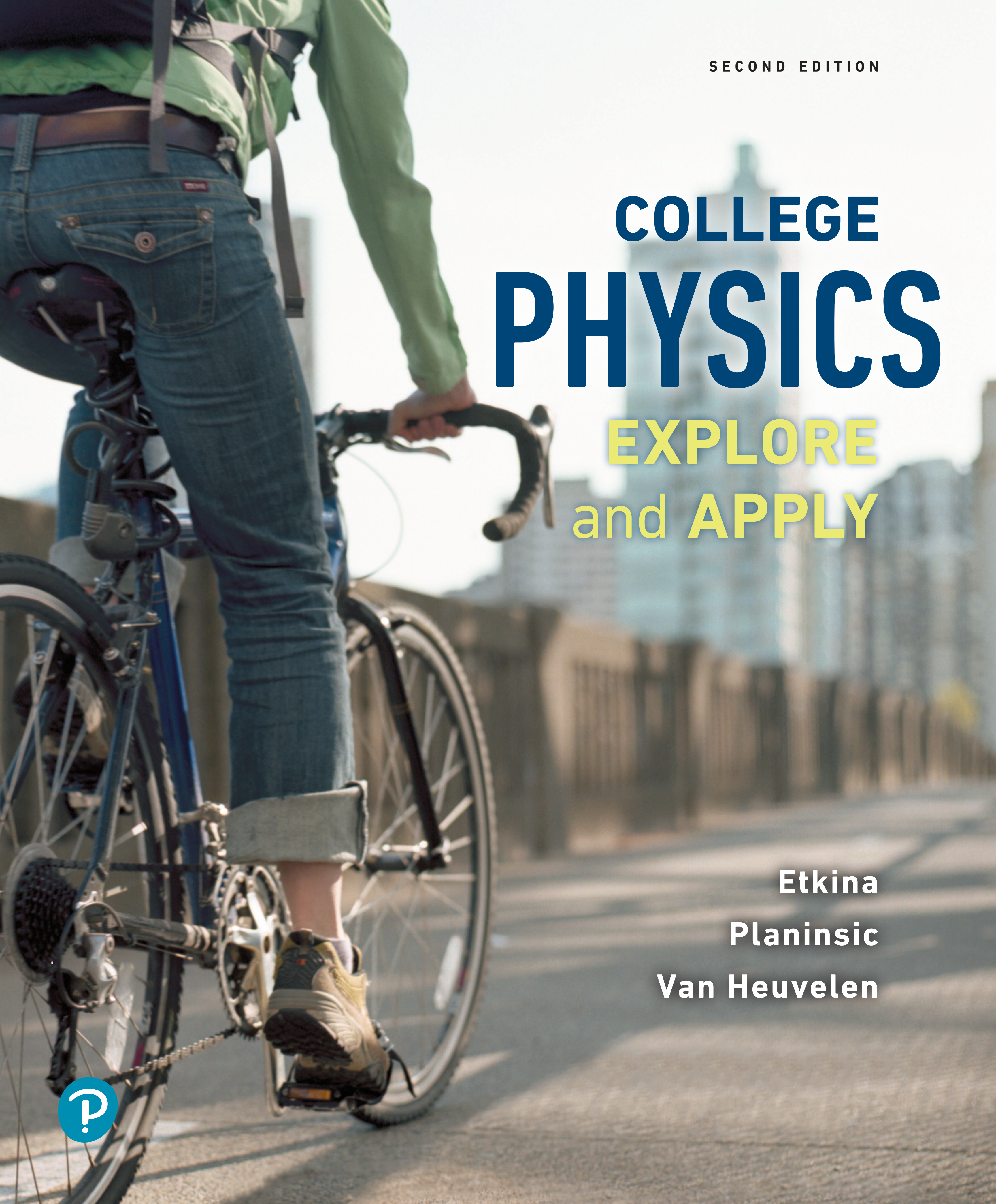

SECOND EDITION

COLLEGE PHYSICS

EXPLORE and APPLY

Etkina

Planinsic

Van Heuvelen

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CONVERSION FACTORS

Length

1 in. = 2.54 cm
1 m = 39.4 in. = 3.28 ft
1 mi = 5280 ft = 1609 m
1 km = 0.621 mi
1 angstrom (Å) = 10^{-10} m
1 light-year (ly) = 9.46×10^{15} m

Volume

1 liter = 1000 cm^3
1 gallon = 3.79 liters

Speed

1 mi/h = 1.61 km/h = 0.447 m/s

Mass

1 atomic mass unit (u) = 1.660×10^{-27} kg
(Earth exerts a 2.205-lb force on an object with 1 kg mass)

Force

1 lb = 4.45 N

Work and Energy

1 ft·lb = 1.356 N·m = 1.356 J
1 cal = 4.180 J
1 eV = 1.60×10^{-19} J
1 kWh = 3.60×10^{6} J

Power

1 W = 1 J/s = 0.738 ft·lb/s
1 hp (U.S.) = 746 W = 550 ft·lb/s
1 hp (metric) = 750 W

Pressure

1 atm = 1.01×10^{5} N/m^2 = 14.7 lb/in^2
= 760 mm Hg
1 Pa = 1 N/m^2

PHYSICAL CONSTANTS

Gravitational coefficient on Earth g	9.81 N/kg
Gravitational constant G	6.67×10^{-11} N·m^2/kg^2
Mass of Earth	5.97×10^{24} kg
Average radius of Earth	6.38×10^{6} m
Density of dry air (STP)	1.3 kg/m^3
Density of water (4 °C)	1000 kg/m^3
Avogadro's number N_A	6.02×10^{23} particles (g atom)
Boltzmann's constant k_B	1.38×10^{-23} J/K
Gas constant R	8.3 J/mol·K
Speed of sound in air (0°)	340 m/s
Coulomb's constant k_C	9.0×10^{9} N·m^2/C^2
Speed of light c	3.00×10^{8} m/s
Elementary charge e	1.60×10^{-19} C
Electron mass m_e	9.11×10^{-31} kg = 5.4858×10^{-4} u
Proton mass m_p	1.67×10^{-27} kg = 1.00727 u
Neutron mass m_n	1.67×10^{-27} kg = 1.00866 u
Planck's constant h	6.63×10^{-34} J·s

POWER OF TEN PREFIXES

Prefix	Abbreviation	Value
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Hecto	h	10^{2}
Deka	da	10^{1}
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Femto	f	10^{-15}

SOME USEFUL MATH

Area of circle (radius r) πr^2
Surface area of sphere $4\pi r^2$
Volume of sphere $\frac{4}{3}\pi r^3$

Trig definitions:
$\sin\theta$ = (opposite side)/(hypotenuse)
$\cos\theta$ = (adjacent side)/(hypotenuse)
$\tan\theta$ = (opposite side)/(adjacent side)

Quadratic equation:
$0 = ax^2 + bx + c,$

where $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Brief Contents

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Help students learn physics by doing physics

Dear Colleague,

Welcome to the second edition of our textbook *College Physics: Explore and Apply* and its supporting materials (Mastering^{TM} Physics, the *Active Learning Guide* (ALG), and our *Instructor's Guide*)—a coherent learning system that helps students **learn physics by doing physics**!

Experiments, experiments… Instead of being presented physics as a static set of established concepts and mathematical relations, students develop their own ideas just as physicists do: they *explore* and analyze **observational experiments**, identify patterns in the data, and propose explanations for the patterns. They then design **testing experiments** whose outcomes either confirm or contradict their explanations. Once tested, students *apply* explanations and relations for practical purposes and to problem solving.

A physics tool kit To build problem-solving skills and confidence, students master proven visual tools (representations such as motion diagrams and energy bar charts) that serve as bridges between words and abstract mathematics and that form the basis of our overarching problem-solving strategy. Our unique and varied problems and activities promote 21st-century competences such as evaluation and communication and reinforce our practical approach with photo, video, and data analysis and real-life situations.

A flexible learning system Students can work collaboratively on ALG activities in class (lectures, labs, and problem-solving sessions) and then read the textbook at home and solve end-of-chapter problems, or they can read the text and do the activities using Mastering Physics at home, then come to class and discuss their ideas. However they study, students will see physics as a living thing, a process in which they can participate as equal partners.

Why a new edition? With a wealth of feedback from users of the first edition, our own ongoing experience and that of a gifted new co-author, and changes in the world in general and in education in particular, we embarked on this second edition in order to refine and strengthen our experiential learning system. Experiments are more focused and effective, our multiple-representation approach is expanded, topics have been added or moved to provide more flexibility, the writing, layout, and design are streamlined, and all the support materials are more tightly correlated to our approach and topics.

Working on this new edition has been hard work, but has enriched our lives as we've explored new ideas and applications. We hope that using our textbook will enrich the lives of your students!

Eugenia Etkina

Gorazd Planinsic

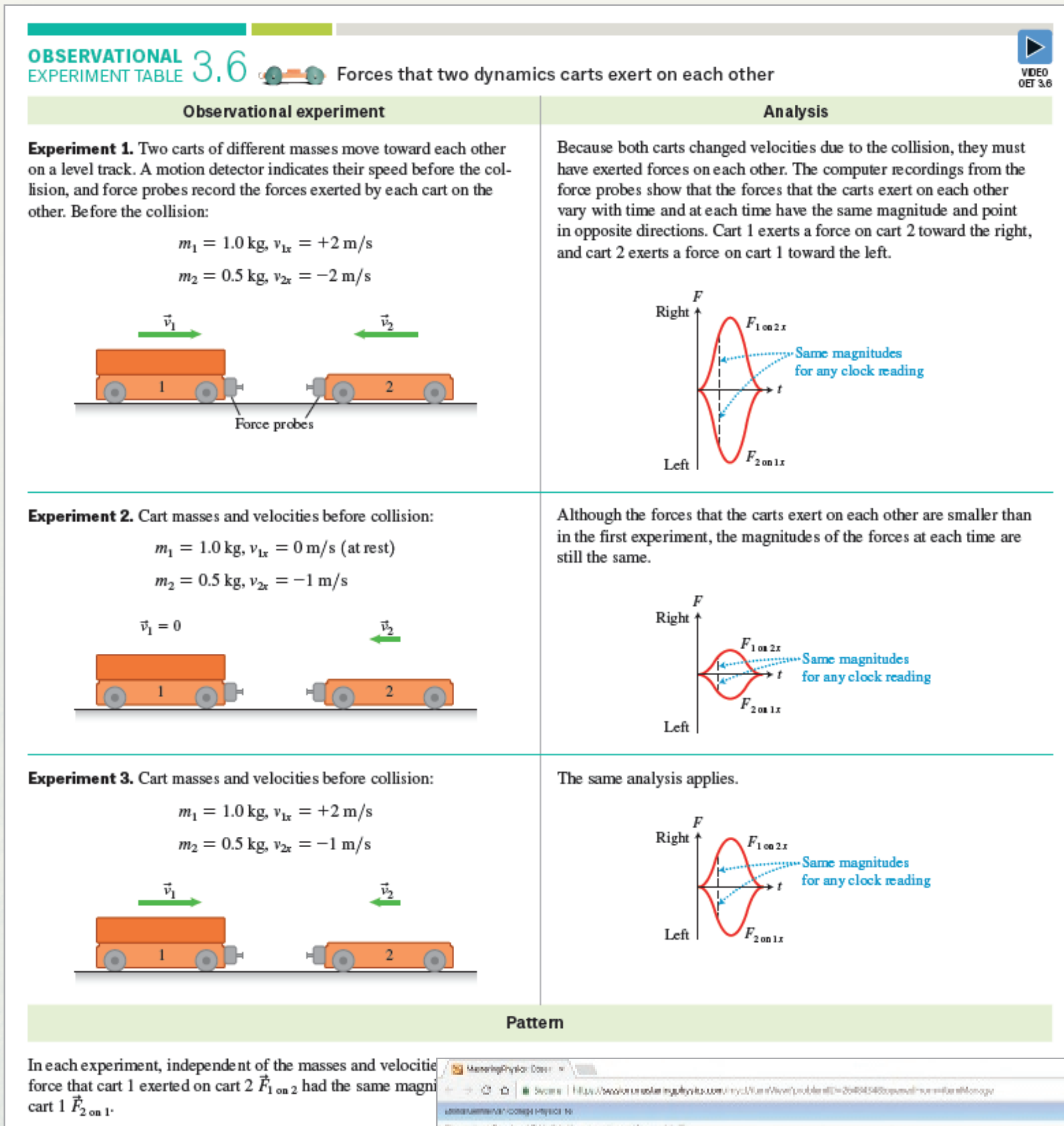
Alan Van Heuvelen

"This book made me think deeper and understand better."

—student at *Horry Georgetown Technical College*

PEARSON

A unique and active learning approach promotes deep and lasting



OBSERVATIONAL EXPERIMENT TABLE 3.6 Forces that two dynamics carts exert on each other

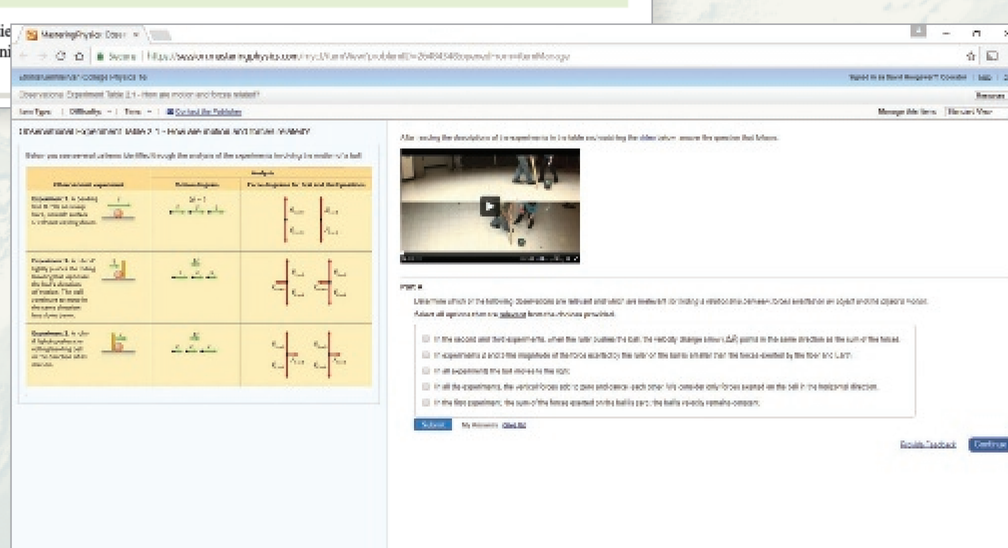
VIDEO OET 3.6

Observational experiment	Analysis
Experiment 1. Two carts of different masses move toward each other on a level track. A motion detector indicates their speed before the collision, and force probes record the forces exerted by each cart on the other. Before the collision: $m_1 = 1.0\ \text{kg},\ v_{1x} = +2\ \text{m/s}$ $m_2 = 0.5\ \text{kg},\ v_{2x} = -2\ \text{m/s}$	Because both carts changed velocities due to the collision, they must have exerted forces on each other. The computer recordings from the force probes show that the forces that the carts exert on each other vary with time and at each time have the same magnitude and point in opposite directions. Cart 1 exerts a force on cart 2 toward the right, and cart 2 exerts a force on cart 1 toward the left.
Experiment 2. Cart masses and velocities before collision: $m_1 = 1.0\ \text{kg},\ v_{1x} = 0\ \text{m/s}$ (at rest) $m_2 = 0.5\ \text{kg},\ v_{2x} = -1\ \text{m/s}$	Although the forces that the carts exert on each other are smaller than in the first experiment, the magnitudes of the forces at each time are still the same.
Experiment 3. Cart masses and velocities before collision: $m_1 = 1.0\ \text{kg},\ v_{1x} = +2\ \text{m/s}$ $m_2 = 0.5\ \text{kg},\ v_{2x} = -1\ \text{m/s}$	The same analysis applies.

Pattern

In each experiment, independent of the masses and velocitie[...] force that cart 1 exerted on cart 2 $\vec{F}_{1\ \text{on}\ 2}$ had the same magni[...] cart 1 $\vec{F}_{2\ \text{on}\ 1}$.

UPDATED! Observational Experiment Tables and Testing Experiment Tables: Students must make observations, analyze data, identify patterns, test hypotheses, and predict outcomes. Redesigned for clarity in the second edition, these tables encourage students to explore science through active discovery and critical thinking, constructing robust conceptual understanding.

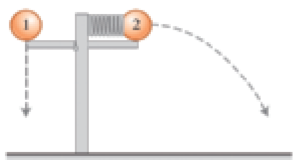


NEW! Digitally Enhanced Experiment Tables now include embedded videos in the Pearson eText for an interactive experience. Accompanying questions are available in Mastering Physics to build skills essential to success in physics.

conceptual understanding of physics and the scientific process

TESTING EXPERIMENT TABLE 4.6 Testing the independence of horizontal and vertical motions

VIDEO TET 4.6

Testing experiment	Prediction	Outcome
At time zero, ball 1 is dropped. Simultaneously, ball 2 is shot horizontally when a compressed spring is released. Which ball hits the surface first? 	Both balls start with zero initial vertical speed; thus their vertical motions are identical. Since we think that the vertical motion is independent of the horizontal motion, we predict that they will land at the same time.	When we try the experiment, the balls do land at the same time.

Conclusion

The outcome supports the hypothesis that horizontal and vertical motions are independent of each other.

> *"I like that the experiment tables... explain in detail why every step was important."*
>
> —student at *Mission College*

EXPANDED! Experiment videos and photos created by the authors enhance the active learning approach. Approximately 150 photos and 40 videos have been added to the textbook, as well as embedded in the Pearson eText, and scores more in the *Active Learning Guide* (ALG).

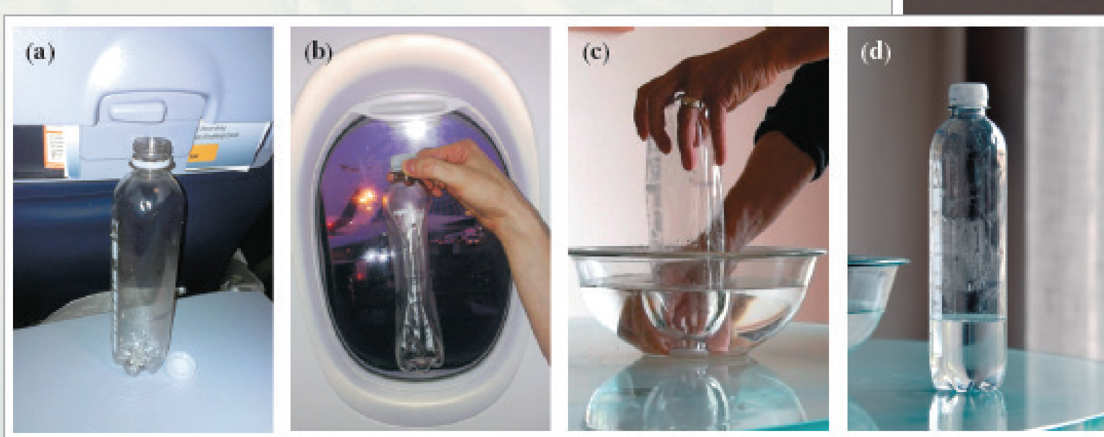
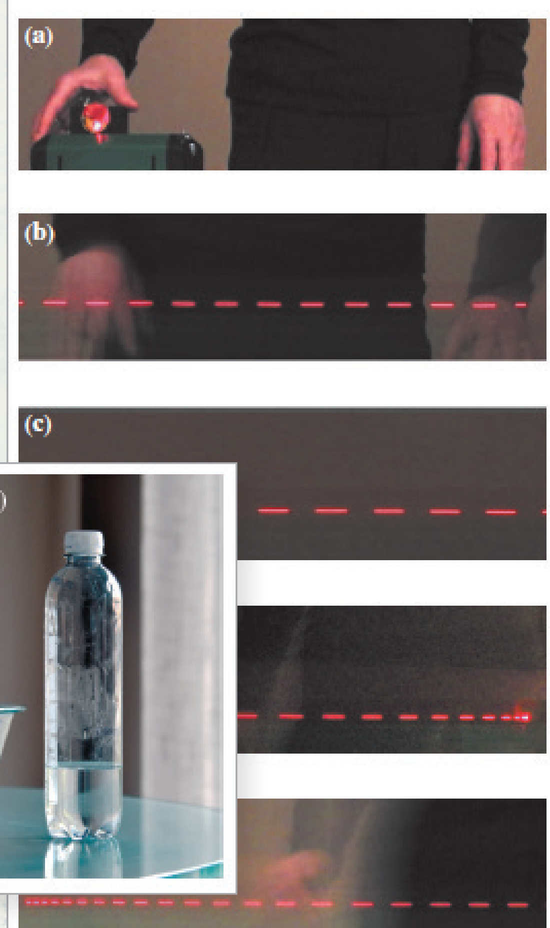
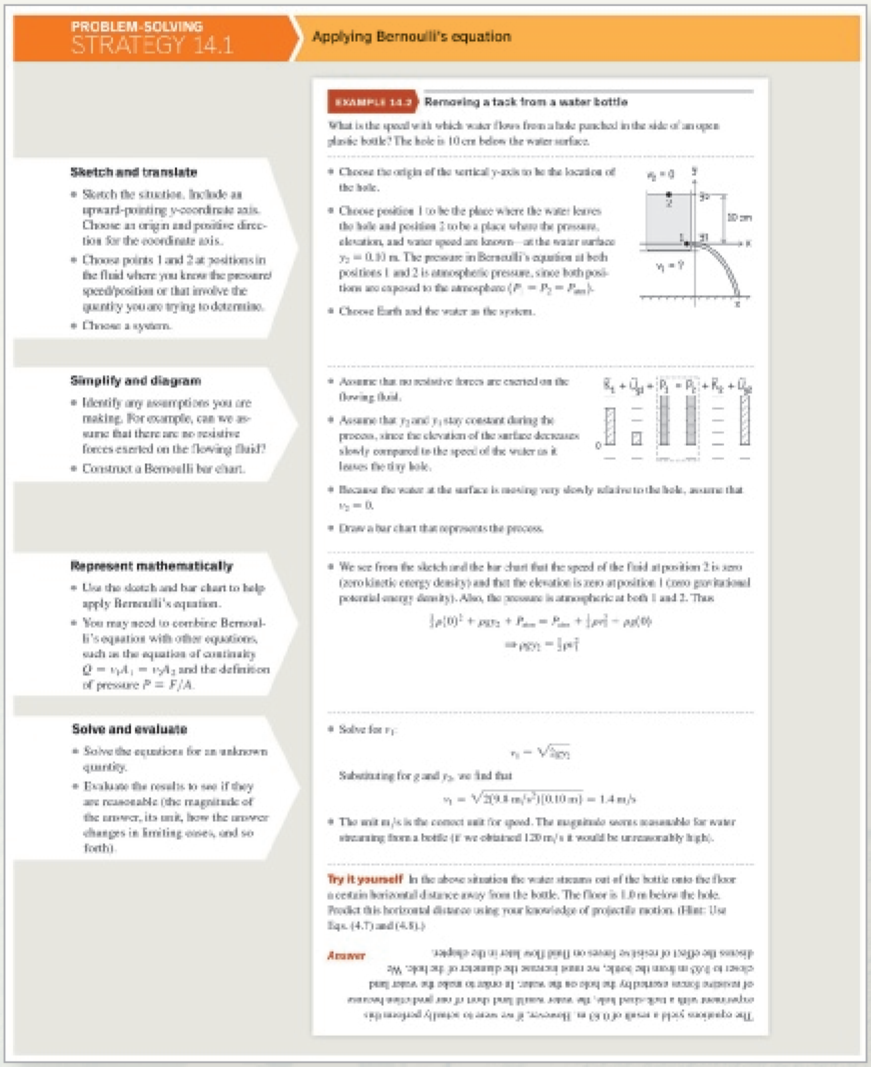


FIGURE 2.2 Long-exposure photographs of a moving cart with a blinking LED.



A wealth of practical and consistent guidance, examples, and opportunities



PROBLEM-SOLVING STRATEGY 14.1 Applying Bernoulli's equation

EXAMPLE 14.2 Removing a tack from a water bottle

What is the speed with which water flows from a hole punched in the side of an open plastic bottle? The hole is 10 cm below the water surface.

Sketch and translate

- Sketch the situation. Include an upward-pointing y-coordinate axis. Choose an origin and positive direction for the coordinate axis.
- Choose points 1 and 2 at positions in the fluid where you know the pressure/speed/position or that involve the quantity you are trying to determine.
- Choose a system.

- Choose the origin of the vertical y-axis to be the location of the hole.
- Choose position 1 to be the place where the water leaves the hole and position 2 to be a place where the pressure, elevation, and water speed are known—at the water surface $y_2 = 0.10$ m. The pressure in Bernoulli's equation at both positions 1 and 2 is atmospheric pressure, since both positions are exposed to the atmosphere ($P_1 = P_2 = P_{atm}$).
- Choose Earth and the water as the system.

Simplify and diagram

- Identify any assumptions you are making. For example, can we assume that there are no resistive forces exerted on the flowing fluid?
- Construct a Bernoulli bar chart.

- Assume that no resistive forces are exerted on the flowing fluid.
- Assume that y_2 and y_1 stay constant during the process, since the elevation of the surface decreases slowly compared to the speed of the water as it leaves the tiny hole.
- Because the water at the surface is moving very slowly relative to the hole, assume that $v_2 = 0$.
- Draw a bar chart that represents the process.

Represent mathematically

- Use the sketch and bar chart to help apply Bernoulli's equation.
- You may need to combine Bernoulli's equation with other equations, such as the equation of continuity $Q = v_1A_1 = v_2A_2$ and the definition of pressure $P = F/A$.

- We see from the sketch and the bar chart that the speed of the fluid at position 2 is zero (zero kinetic energy density) and that the elevation is zero at position 1 (zero gravitational potential energy density). Also, the pressure is atmospheric at both 1 and 2. Thus

$$\tfrac{1}{2}\rho(0)^2 + \rho g y_2 + P_{atm} = P_{atm} + \tfrac{1}{2}\rho v_1^2 + \rho g(0)$$
$$\Rightarrow \rho g y_2 = \tfrac{1}{2}\rho v_1^2$$

Solve and evaluate

- Solve the equations for an unknown quantity.
- Evaluate the results to see if they are reasonable (the magnitude of the answer, its unit, how the answer changes in limiting cases, and so forth).

- Solve for v_1:

$$v_1 = \sqrt{2gy_2}$$

Substituting for g and y_2, we find that

$$v_1 = \sqrt{2(9.8\ \text{m/s}^2)(0.10\ \text{m})} = 1.4\ \text{m/s}$$

- The unit m/s is the correct unit for speed. The magnitude seems reasonable for water streaming from a bottle (if we obtained 120 m/s it would be unreasonably high).

Try it yourself In the above situation the water streams out of the bottle onto the floor a certain horizontal distance away from the bottle. The floor is 1.0 m below the hole. Predict this horizontal distance using your knowledge of projectile motion. (Hint: Use Eqs. (4.7) and (4.8).)

Answer The equations yield a result of 0.63 m. However, if we were to actually perform this experiment with a tack-sized hole, the water would land short of our prediction because of resistive forces exerted by the hole on the water. In order to make the water land closer to 0.63 m from the bottle, we must increase the diameter of the hole. We discuss the effect of resistive forces on fluid flow later in the chapter.

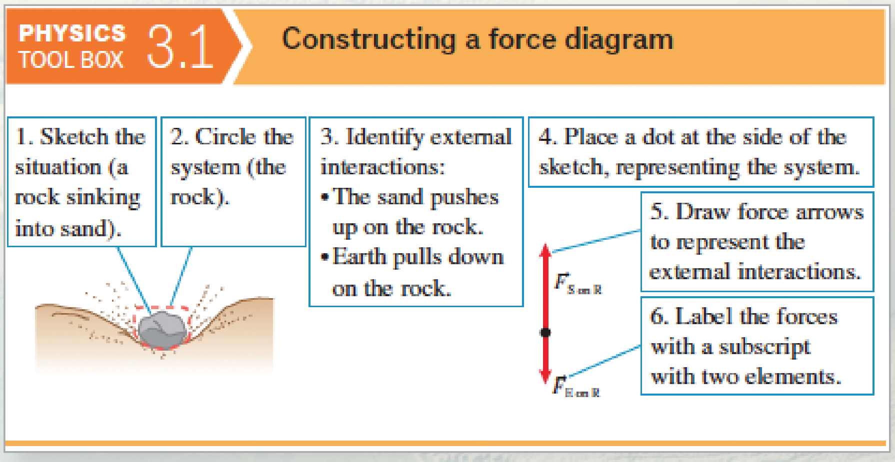
A four-step problem-solving approach in worked examples

consistently uses multiple representations to teach students how to solve complex physics problems. Students follow the steps of **Sketch & Translate, Simplify & Diagram, Represent Mathematically, Solve & Evaluate** to translate a problem statement into the language of physics, sketch and diagram the problem, represent it mathematically, solve the problem, and evaluate the result.

Physics Tool Boxes focus on a particular skill, such as drawing a motion diagram, force diagram, or work-energy bar chart, to help students master the key tools they will need to utilize throughout the course to analyze physics processes and solve problems, bridging real phenomena and mathematics.

"It made me excited to learn physics! It has a systematic and easy-to-understand method for solving problems."

—student at State University of West Georgia



for practice help develop confidence and higher-level reasoning skills

56. * A frog jumps at an angle 30° above the horizontal. The origin of the coordinate system is at the point where the frog leaves the ground. Complete Table P4.55 by drawing check marks in the cells that correctly connect the quantities in the first column that describe the motion of the frog and the descriptions of what is happening to these quantities while the frog is moving. Consider the frog as a point-like object and assume that the resistive force exerted by the air is negligible.

TABLE P4.55

Physical quantity	Remains constant	Is changing	Increases only	Decreases only	Increases, then decreases	Decreases, then increases
x-coordinate magnitude						
y-coordinate magnitude						
Direction of velocity						
Magnitude of velocity						
Direction of acceleration						
Magnitude of acceleration						

29. * Your friend Devin has to solve the following problem: "You have a spring with spring constant k. You compress it by distance x and use it to shoot a steel ball of mass m into a sponge of mass M. After the collision, the ball and the sponge move a distance s along a rough surface and stop (see Figure P7.29). The coefficient of friction between the sponge and the surface is μ. Derive an expression that shows how the distance s depends on relevant physical quantities."

FIGURE P7.29

Devin derived the following equation:

$$s = \frac{kmx^2}{2(m + M)^2 g\mu}$$

Without deriving it, evaluate the equation that reasonable? How do you know?

NEW! Problem types include multiple choice with multiple correct answers, find-a-pattern in data presented in a video or a table, ranking tasks, evaluate statements/claims/explanations/measuring procedures, evaluate solutions, design a device or a procedure that meets given criteria, and linearization problems, promoting critical thinking and deeper understanding.

"It helps break down the problems, which makes them look less daunting when compared to paragraphs of explanations. It is very straightforward."

—student at Case Western Reserve University

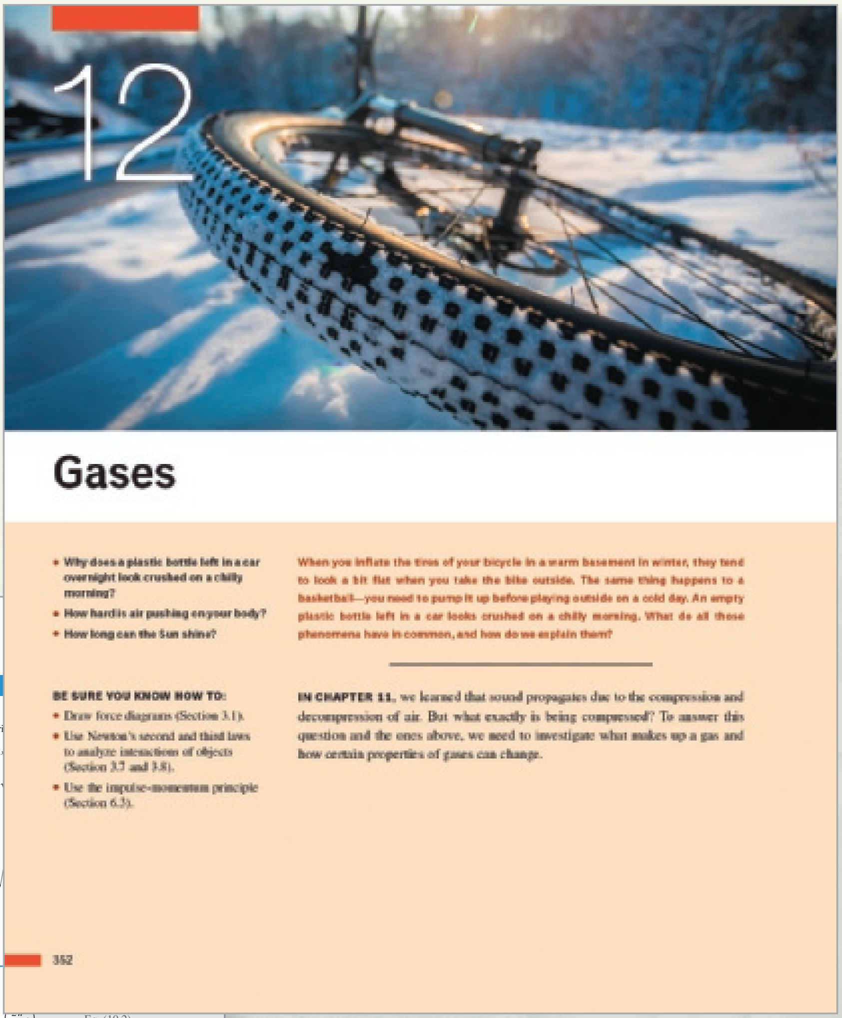
59. * Jeff and Natalie notice that a rubber balloon, which is first in a warm room, shrinks when they take it into the garden on a cold winter day. They propose two different explanations for the observed phenomenon: (a) the balloon is slowly leaking; (b) the balloon shrinks due to decreased temperature while the pressure in the balloon remains constant (isobaric compression). In order to test their proposed explanations, Jeff and Natalie perform three consecutive experiments: they measure the volume of the balloon and the temperature of the air near the balloon (1) in the room, (2) in the garden, and (3) again in the room. Their measurements, including uncertainties, are presented in the table below.

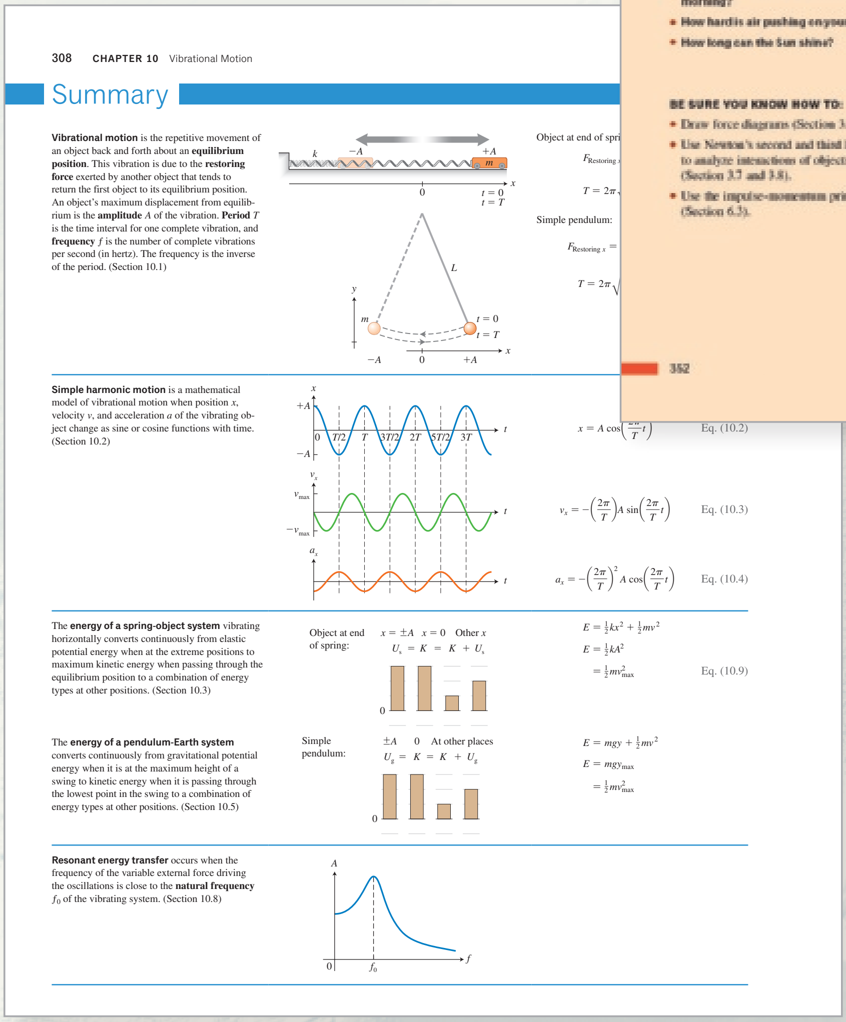
Exp. #	Location	Temperature	Volume of the balloon
1	Room	26.2 °C ± 0.1 °C	$7500\ \text{cm}^3 \pm 400\ \text{cm}^3$
2	Garden	−15.3 °C ± 0.1 °C	$6400\ \text{cm}^3 \pm 400\ \text{cm}^3$
3	Room	26.2 °C ± 0.1 °C	$7300\ \text{cm}^3 \pm 400\ \text{cm}^3$

Based on the data, can Jeff and Natalie reject any of their hypotheses? Explain. Make sure you include uncertainties in your answer.

Pedagogically driven design and content changes

NEW! A fresh and modern design with a more transparent hierarchy of features and navigation structure, as well as an engaging chapter opener page and streamlined chapter summary, result in a more user-friendly resource, both for learning and for reference.

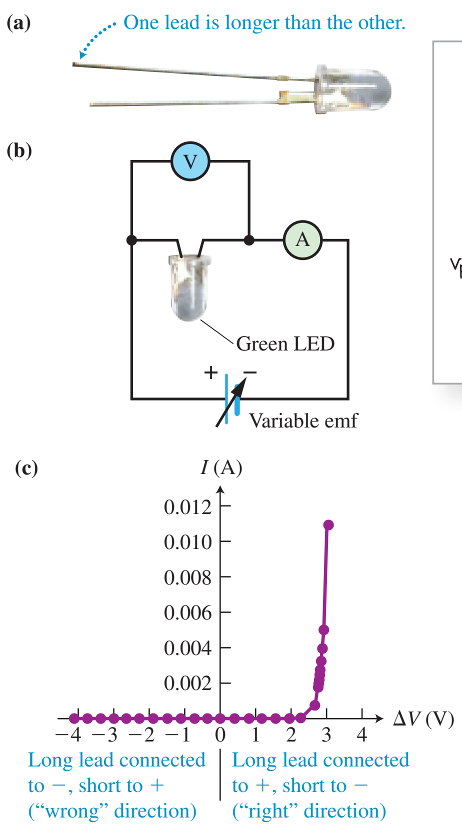




REVISED! Streamlined text, layout, and figures throughout the book enhance the focus on central themes and topics, eliminating extraneous detail, resulting in **over 150 fewer pages** than the first edition and allowing students to study more efficiently.

enhance ease of use for students and instructors alike

FIGURE 19.14 A green LED. The electric circuit in (b) is used to collect the I-versus-ΔV data plotted in (c).



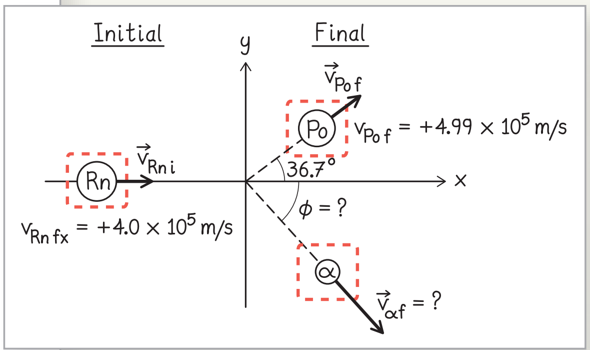
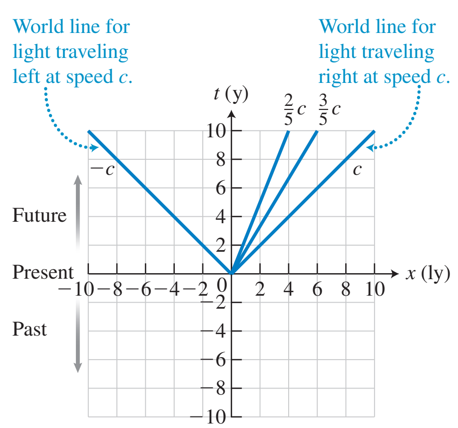
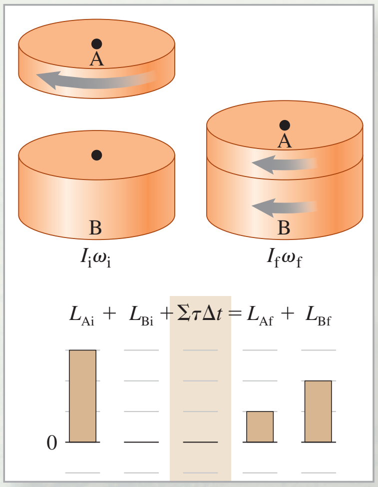


FIGURE 26.11 World lines for two objects and two light beams drawn on a spacetime diagram.



NEW, REVISED, and EXPANDED! Topics include capacitors, AC circuits, LEDs, friction, 2-D collisions, energy, bar charts for rotational momentum and nuclear energy, ideal gas processes, thermodynamic engines, semiconductors, velocity selectors, and spacetime diagrams in special relativity.



NEW! Integration of vector arithmetic into early chapters helps students develop vector-related skills in the context of learning physics. **Earlier placement of waves and oscillations** allows instructors to teach these topics with mechanics if preferred. Coverage with optics is also possible.

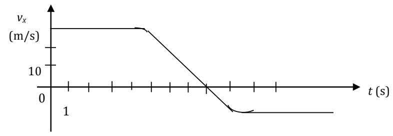
A flexible learning system adapts to any method of instruction

2.9.9 Evaluate the solution

Class: *Equipment per group: whiteboard and markers*

Discuss with your group: Identify any errors in the proposed solution to the following problem and provide a corrected solution if there are errors.

Problem: Use the graphical representation of motion to determine how far the object travels until it stops.

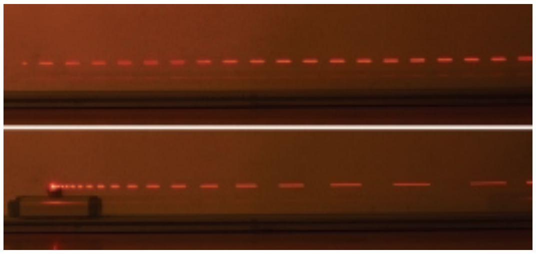


Proposed solution The object was at rest for about 5 seconds, then started moving in the negative direction and stopped after about 9 seconds. During this time its position changed from 30 m to – 10 m, so the total distance that it traveled was 40 m.

2.9.10 Observe and analyze

Class: *Equipment per group: whiteboard and markers*

Collaborate together with your group to figure this out: The figure below shows long exposure photos of two experiments with a blinking LED that was fixed on a moving cart. In both cases the cart was moving from right to left. The duration of the ON and OFF time for LED is 154 ms and the length of the cart is 17 cm. a) Specify the coordinate system and draw a qualitative velocity-time graph for the motion of the cart in both experiments; b) estimate the speed of the cart in the first experiment. Both photos were obtained from the same spot and with the same settings. Indicate any assumptions that you made.



REVISED! The **Active Learning Guide** aligns with the textbook's chapters and supplements the knowledge-building approach of the textbook with activities that provide opportunities for further observation, testing, sketching, and analysis as well as collaboration, scientific reasoning, and argumentation. The *Active Learning Guide* can be used in class for individual or group work or assigned as homework and is now better integrated with the text. Now available via download in the Mastering Instructor Resource Center and customizable in print form via Pearson Collections.

> *"It is much easier to understand a concept when you can see it in action, and not just read it."*
>
> **—student at *San Antonio College***

The **Instructor's Guide** provides key pedagogical principles of the textbook and elaborates on the implementation of the methodology used in the textbook, providing guidance on how to integrate the approach into your course.

2

Kinematics: Motion in One Dimension

In Chapter 2, students will learn to describe motion using sketches, motion diagrams, graphs, and algebraic equations. The chapter subject matter is broken into four parts:

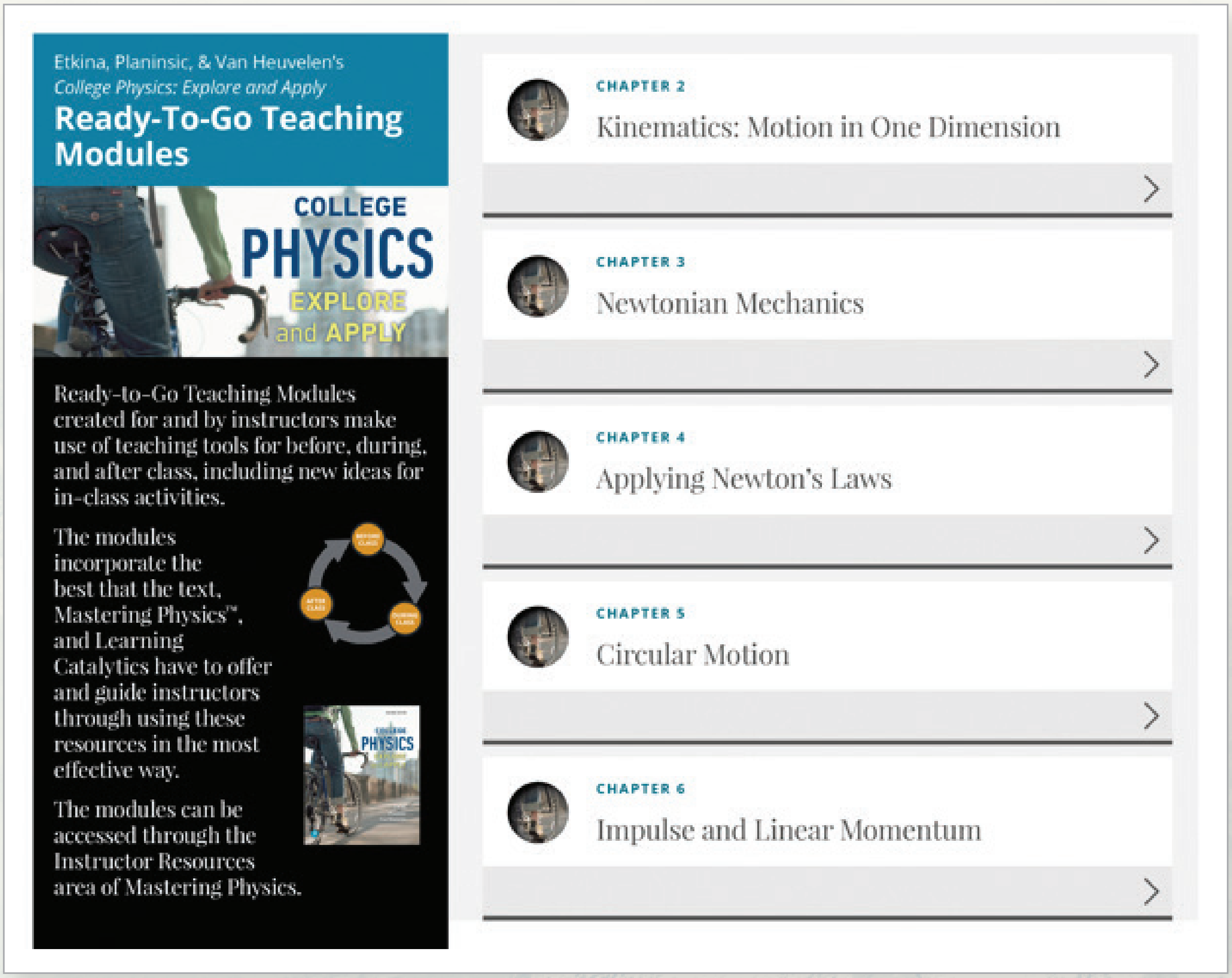
I. *What is motion and how do we describe it qualitatively?*
II. *Some of the quantities used to describe motion and a graphical description of motion*
III. *Use of the above to describe constant velocity and constant acceleration motion*
IV. *Developing and using the skills needed to analyze motion in real processes*

For each part, we provide examples of activities that can be used in the classroom, brief discussions of why we introduce the content in a particular order and use of these activities to support the learning, and common student difficulties.

Chapter subject matter	Related textbook section	ALG activities	End-of-chapter questions and problems	Videos
What is motion and how do we describe it qualitatively?	2.1, 2.2	2.1.1–2.1.6, 2.2.1–2.2.4	Problems 1, 3	OET 2.1

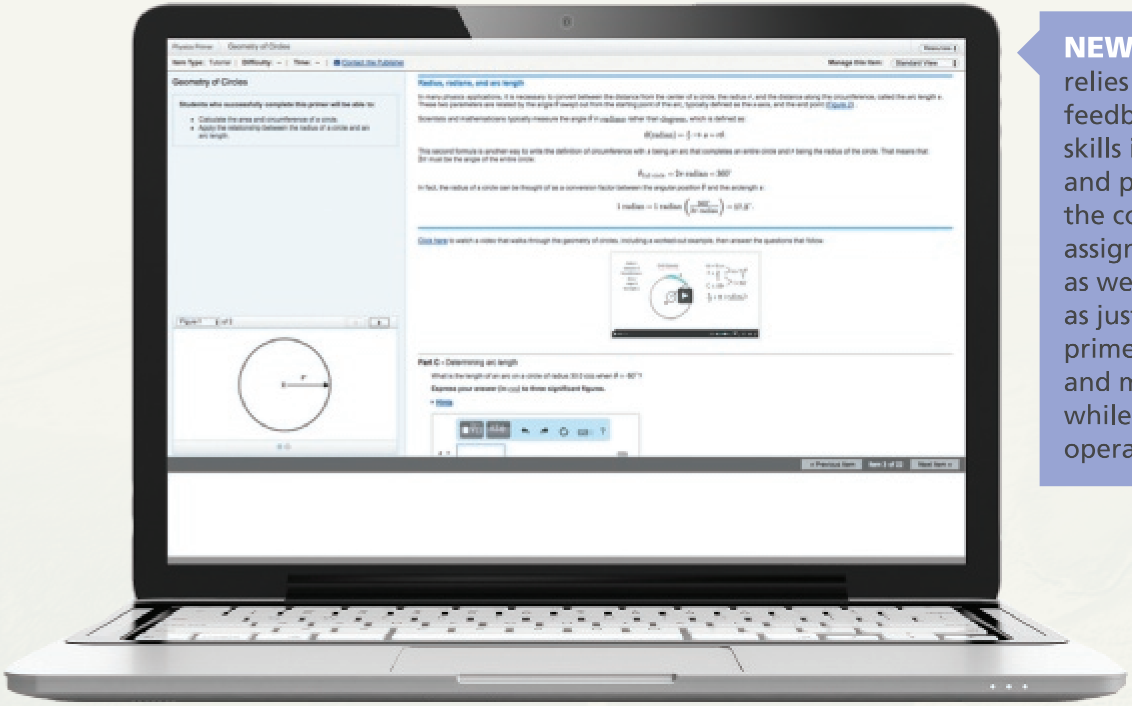
and provides tools for easy implementation

NEW! Ready-to-Go Teaching Modules created for and by instructors make use of teaching tools for before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, Mastering Physics, and Learning Catalytics have to offer and guide instructors through using these resources in the most effective way. The modules can be accessed through the Instructor Resources area of Mastering Physics and as pre-built, customizable assignments.



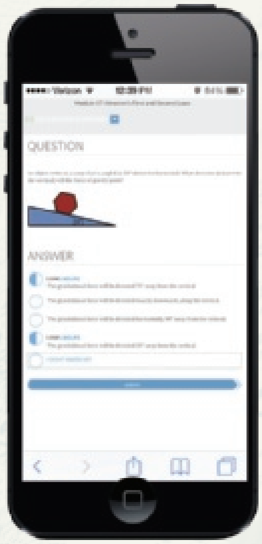
Mastering Physics

Build a basic understanding of physics principles and math skills



NEW! The Physics Primer relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepare them for success in the course. These tutorials can be assigned before the course begins as well as throughout the course as just-in-time remediation. The primer ensures students practice and maintain their math skills, while tying together mathematical operations and physics analysis.

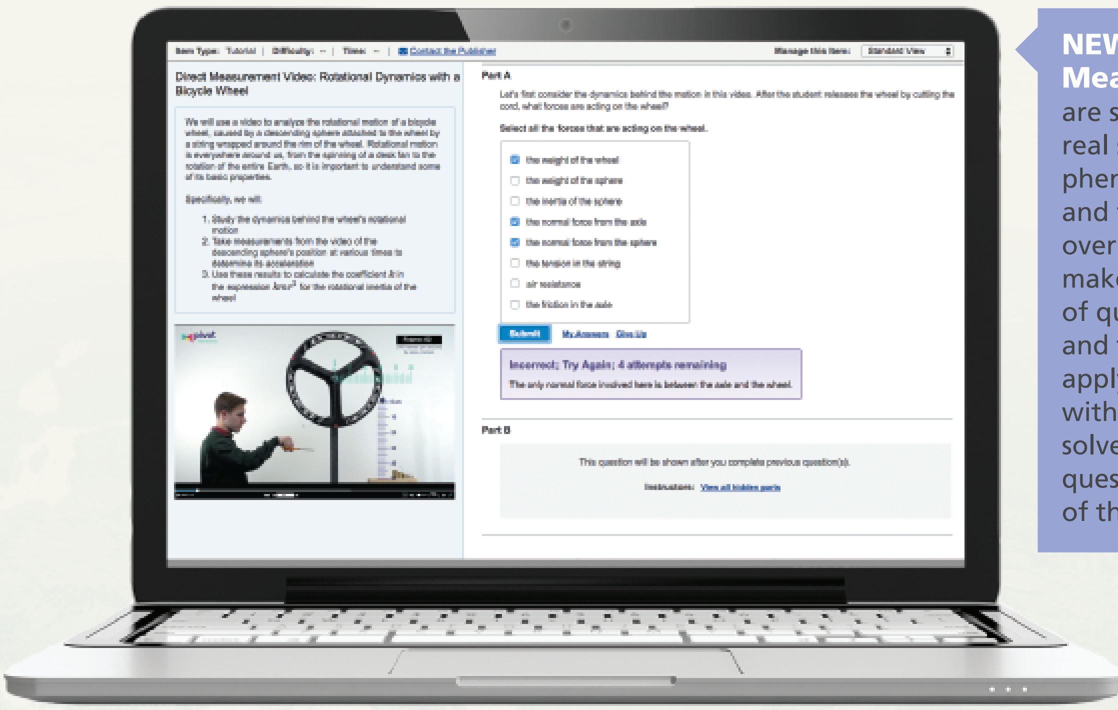
Interactive Animated Videos provide an engaging overview of key topics with embedded assessment to help students check their understanding and to help professors identify areas of confusion. Note that these videos are not tied to the textbook and therefore do not use the language, symbols, and conceptual approaches of the book and ALG. The authors therefore recommend assigning these videos after class to expose students to different terminology and notation that they may come across from other sources.



Dynamic Study Modules (DSMs) help students study effectively on their own by continuously assessing their activity and performance in real time and adapting to their level of understanding. The content focuses on definitions, units, and the key relationships for topics across all of mechanics and electricity and magnetism.

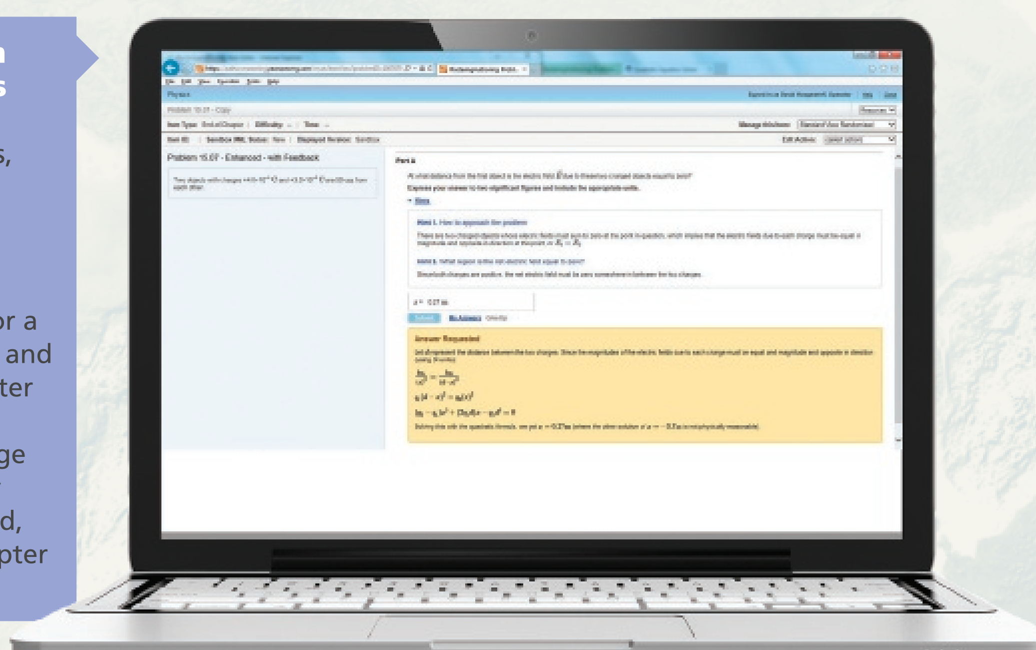
www.MasteringPhysics.com

Show connections between physics and the real world as students learn to apply physics concepts via enhanced media

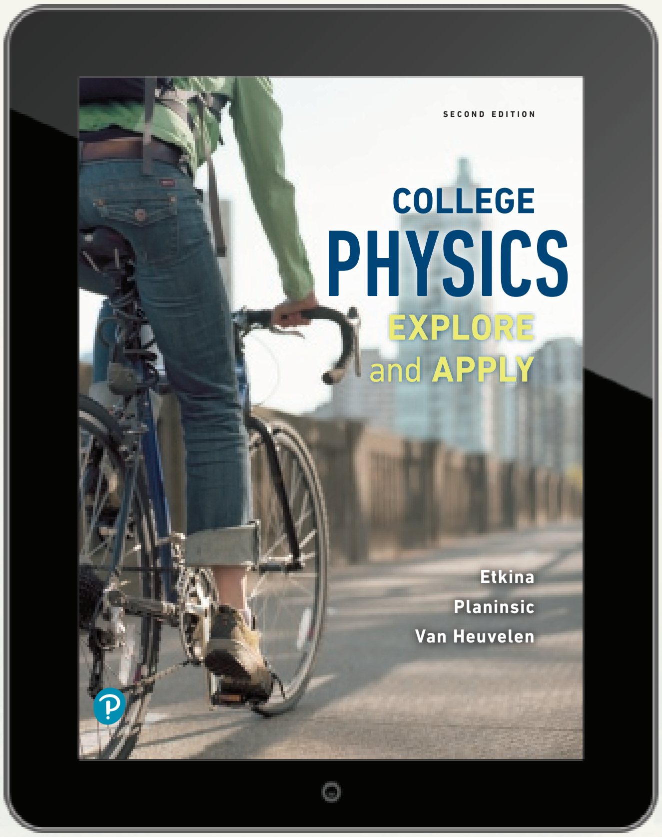


NEW! Direct Measurement Videos are short videos that show real situations of physical phenomena. Grids, rulers, and frame counters appear as overlays, helping students to make precise measurements of quantities such as position and time. Students then apply these quantities along with physics concepts to solve problems and answer questions about the motion of the objects in the video.

NEW! End-of-chapter problem types and 15% new questions and problems include multiple choice with multiple correct answers, find-a-pattern in data presented in a video or a table, ranking tasks, evaluate statements/claims/explanations/measuring procedures, evaluate solutions, design a device or a procedure that meets given criteria, and linearization problems. End-of-chapter problems have undergone careful analysis using Mastering Physics usage data to provide fine-tuned difficulty ratings and to produce a more varied, useful, and robust set of end-of-chapter problems.



Give students **fingertip access** to interactive tools



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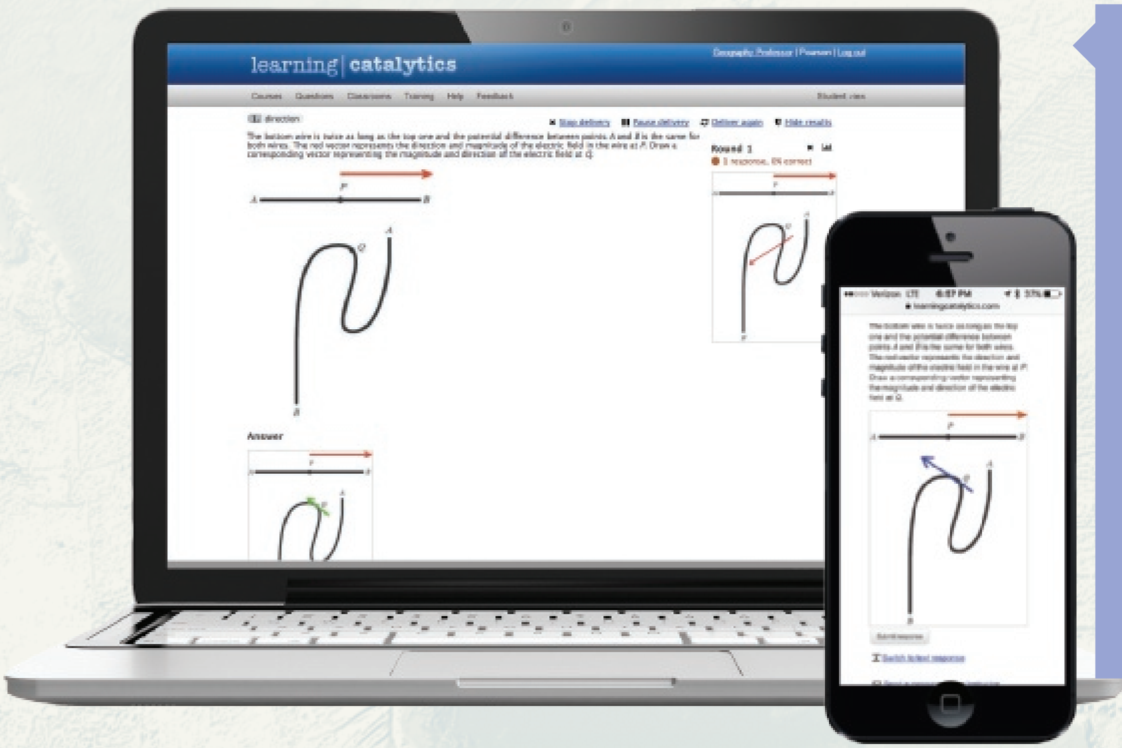

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COLLEGE

PHYSICS

EXPLORE and APPLY

second edition

COLLEGE PHYSICS

EXPLORE and APPLY

Eugenia Etkina
RUTGERS UNIVERSITY

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UNIVERSITY OF LJUBLJANA

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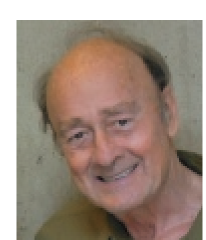
EUGENIA ETKINA is a Distinguished Professor at Rutgers, the State University of New Jersey. She holds a PhD in physics education from Moscow State Pedagogical University and has more than 35 years of experience teaching physics. She is a recipient of the 2014 Millikan Medal, awarded to educators who have made significant contributions to teaching physics, and is a fellow of the AAPT. Professor Etkina designed and now coordinates one of the largest programs in physics teacher preparation in the United States, conducts professional development for high school and university physics instructors, and participates in reforms to the undergraduate physics courses. In 1993 she developed a system in which students learn physics using processes that mirror scientific practice. That system, called *Investigative Science Learning Environment* (ISLE), serves as the basis for this textbook. Since 2000, Professor Etkina has conducted over 100 workshops for physics instructors, and she co-authored the first edition of *College Physics* and the *Active Learning Guide*. Professor Etkina is a dedicated teacher and an active researcher who has published over 60 peer-refereed articles.

GORAZD PLANINSIC is a Professor of Physics at the University of Ljubljana, Slovenia. He has a PhD in physics from the University of Ljubljana. Since 2000 he has led the Physics Education program, which prepares almost all high school physics teachers in the country of Slovenia. He started his career in MRI physics and later switched to physics education research. During the last 10 years, his work has mostly focused on the research of new experiments and how to use them more productively in teaching and learning physics. He is co-founder of the Slovenian hands-on science center House of Experiments. Professor Planinsic is co-author of more than 80 peer-refereed research articles and more than 20 popular science articles, and is the author of a university textbook for future physics teachers. In 2013 he received the Science Communicator of the Year award from the Slovenian Science Foundation.

ALAN VAN HEUVELEN holds a PhD in physics from the University of Colorado. He has been a pioneer in physics education research for several decades. He taught physics for 28 years at New Mexico State University, where he developed active learning materials including the *Active Learning Problem Sheets* (the *ALPS Kits*) and the *ActivPhysics* multimedia product. Materials such as these have improved student achievement on standardized qualitative and problem-solving tests. In 1993 he joined Ohio State University to help develop a physics education research group. He moved to Rutgers University in 2000 and retired in 2008. For his contributions to national physics education reform, he won the 1999 AAPT Millikan Medal and was selected a fellow of the American Physical Society. Over the span of his career he has led over 100 workshops on physics education reform. He worked with Professor Etkina in the development of the *Investigative Science Learning Environment* (ISLE) and co-authored the first edition of *College Physics* and the *Active Learning Guide*.



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Preface

To the student

College Physics: Explore and Apply is more than just a book. It's a learning *companion*. As a companion, the book won't just tell you about physics; it will act as a guide to help you build physics ideas using methods similar to those that practicing scientists use to construct knowledge. The ideas that you build will be *yours*, not just a copy of someone else's ideas. As a result, the ideas of physics will be much easier for you to use when you need them: to succeed in your physics course, to obtain a good score on exams such as the MCAT, and to apply to everyday life.

Although few, if any, textbooks can honestly claim to be a pleasure to read, *College Physics: Explore and Apply* is designed to make the process interesting and engaging. The physics you learn in this book will help you understand many real-world phenomena, from why giant cruise ships are able to float to how telescopes work. The cover of the book communicates its spirit: you learn physics by exploring the natural world and applying it in your everyday life.

A great deal of research has been done over the past few decades on how students learn. We, as teachers and researchers, have been active participants in investigating the challenges students face in learning physics. We've developed unique strategies that have proven effective in helping students think like physicists. These strategies are grounded in *active learning with your peers*—deliberate, purposeful action on your part to learn something new. For learning to happen, one needs to talk to others, share ideas, listen, explain, and argue. It is in these deliberations that new knowledge is born. Learning is not passively memorizing so that you can repeat it later. When you learn actively, you engage with the material and—most importantly—share your ideas with others. You relate it to what you already know and benefit from the knowledge of your peers. You think about the material in as many different ways as you can. You ask yourself questions such as "Why does this make sense?" and "Under what circumstances does this not apply?" Skills developed during this process will be the most valuable in your future, no matter what profession you choose.

This book (your learning companion) includes many tools to support the active learning process: each problem-solving tool, worked example, observational experiment table, testing experiment table, review question, and end-of-chapter question and problem is designed to help you build your understanding of physics. To get the most out of these tools and the course, stay actively engaged in the process of developing ideas and applying them; form a learning group with your peers and try to work on the material together. When things get challenging, don't give up.

At this point you should turn to Chapter 1, Introducing Physics, and begin reading. That's where you'll learn the details of the approach that the book uses, what physics is, and how to be successful in the physics course you are taking.

To the instructor

Welcome to the second edition of *College Physics: Explore and Apply* and its supporting materials (Mastering™ Physics, the *Active Learning Guide* (ALG), and the *Instructor's Guide*), a coherent learning system that helps our students learn physics as an ongoing process rather than a static set of established concepts and mathematical relations. It is based on a framework known as ISLE (the *Investigative Science Learning Environment*). This framework originated in the work of Eugenia Etkina in the early 1990s. She designed a logical progression of student learning of physics that mirrors the processes in which physicists engage while constructing and applying knowledge. This progression was enriched in the early 2000s when Alan Van Heuvelen added his multiple representation approach. While logical flow represents a path for thinking, multiple representations are thinking tools. Since 2001, when ISLE curriculum development began, tens of thousands of students have been exposed to it as hundreds of instructors used the materials produced by the authors and their collaborators. Research on students learning physics through ISLE has shown that these students not only master the content of physics, but also become expert problem solvers, can design and evaluate their own experiments, communicate, and most importantly see physics as a process based on evidence as opposed to a set of rules that come from the book.

Experiments, experiments… The main feature of this system is that students practice developing physics concepts by following steps similar to those physicists use when developing and applying knowledge. The first introduction to a concept or a relation happens when students observe simple experiments (called **observational experiments**). Students learn to analyze these experiments, find patterns (either qualitative or quantitative) in the data, and develop multiple explanations for the patterns or quantitative relations. They then learn how to test the explanations and relations in new **testing experiments**. Sometimes the outcomes of the experiments might cause us to reject the explanations; often, they help us keep them. Students see how scientific ideas develop from evidence and are tested by evidence, and how evidence sometimes causes us to reject the proposed explanations. Finally, students learn how tested explanations and relations are applied for practical purposes and in problem solving. This is the process behind the subtitle of the book.

Explore and apply To help students explore and apply physics, we introduce them to tools: physics-specific representations, such as motion and force diagrams, momentum and energy bar charts, ray diagrams, and so forth. These representations serve as bridges between words and abstract mathematics. Research shows that students who use representations other than mathematics to solve problems are much more successful than those who just look for equations. We use a representations-based problem-solving strategy that helps students approach problem solving without fear and eventually develop not only problem-solving skills, but also confidence. The textbook and ALG introduce a whole library of novel problems and activities that help students develop competencies necessary for success in the 21st century: argumentation, evaluation, estimation, and communication. We use photo and video analysis, real-time data, and real-life situations to pose problems.

A flexible learning system There are multiple ways to use our learning system. Students can work collaboratively on ALG activities in class (lectures, labs, and problem-solving sessions) and then read the textbook and solve end-of-chapter problems at home, or they can first read the text and do the activities using Mastering Physics at home, then come to class and discuss their ideas. However they study, students will see physics as a living thing, a process in which they can participate as equal partners.

The key pedagogical principles of this book are described in detail in the first chapter of the *Instructor's Guide* that accompanies *College Physics*—please read that chapter. It elaborates on the implementation of the methodology that we use in this book and provides guidance on how to integrate the approach into your course.

While our philosophy informs *College Physics*, you need not fully subscribe to it to use this textbook. We've organized the book to fit the structure of most algebra-based physics courses: we begin with kinematics and Newton's laws, then move on to conserved quantities, statics, vibrations and waves, gases, fluids, thermodynamics, electricity and magnetism, optics, and finally modern physics. The structure of each chapter will work with any method of instruction. You can assign all of the innovative experimental tables and end-of-chapter problems, or only a few. The text provides thorough treatment of fundamental principles, supplementing this coverage with experimental evidence, new representations, an effective approach to problem solving, and interesting and motivating examples.

New to this edition

There were three main reasons behind the revisions in this second edition. (1) Users provided lots of feedback and we wanted to respond to it. (2) We (the authors) grew and changed, and learned more about how to help students learn, and our team changed—we have a new co-author, who is an expert in educational physics experiments and in the development of physics problems. (3) Finally, we wanted to respond to changes in the world (new physics discoveries, new technology, new skills required in the workplace) and to changes in education (the Next Generation Science Standards, reforms in the AP and MCAT exams). Our first edition was already well aligned with educational reforms, but the second edition strengthens this alignment even further.

We have therefore made the following global changes to the textbook, in addition to myriad smaller changes to individual chapters and elements:

- **An enhanced experiential approach**, with more experiment videos and photos (all created by the authors) and an updated and more focused and effective set of experiment tables, strengthens and improves the core foundation of the first edition. Approximately 150 photos and 40 videos have been added to the textbook, and even more to the ALG.
- **An expanded introductory chapter** (now Chapter 1) gives students a more detailed explanation of "How to use this book" to ensure they get the most out of the chapter features, use them actively, and learn how to think critically.
- **Integration of vector arithmetic in early chapters** allows students to develop vector-related skills in the context of learning physics, rather than its placement in an appendix in the first edition.
- **Earlier placement of waves and oscillations** allows instructors to teach these topics with mechanics if preferred. Coverage with optics is also still possible.
- **Significant new coverage of capacitors, AC circuits, and LEDs** (LEDs now permeate the whole book) expand the real-world and up-to-date applications of electricity.
- **Other new, revised, or expanded topics** include friction, 2-D collisions, energy, bar charts for rotational momentum and nuclear energy, ideal gas processes, thermodynamic engines, semiconductors, velocity selectors, and spacetime diagrams in special relativity.
- **Applications are integrated throughout each chapter,** rather than being grouped in the "Putting it all together" sections of the first edition, in order to optimize student engagement.
- **Problem-solving guidance is strengthened** by the careful revision of many Problem-Solving Strategy boxes and the review of each chapter's set of worked examples. The first edition Reasoning Skill boxes are renamed Physics Tool Boxes to better reflect their role; many have been significantly revised.
- **Streamlined text, layout, and figures** throughout the book enhance the focus on central themes and topics, eliminating extraneous detail. The second edition has over 150 fewer pages than the first edition, and the art program is updated with over 450 pieces of new or significantly revised art.
- **21st-century skills incorporated into many new worked examples and end-of-chapter problems** include data analysis, evaluation, and argumentation. Roughly 15% of all end-of-chapter questions and problems are new.
- **Careful analysis of Mastering Physics usage data** provides fine-tuned difficulty ratings and a more varied, useful, and robust set of end-of-chapter problems.
- **A fresh and modern design** provides a more transparent hierarchy of features and navigation structure, as well as an engaging chapter-opening page and streamlined chapter summary.

- **A significantly revised *Active Learning Guide*** is better integrated with the textbook, following the section sequence, and emphasizes collaboration, scientific reasoning, and argumentation.

All of the above sounds like a lot of work—and it was! But it was also lots of fun: we took photos of juice bottles sinking in the snow, we chased flying airplanes and running water striders, we drove cars with coffee cups on dashboards. Most exciting was our trip to a garbage plant to study and photograph the operation of an eddy current waste separator. Working on this new edition has enriched our lives, and we hope that using our textbook will enrich the lives of your students!

Instructor supplements

TIP All of the following materials are available for download on the Mastering Physics Instructor Resources page.

The **Instructor's Guide** (ISBN 0-134-89031-0), written by Eugenia Etkina, Gorazd Planinsic, David Brookes, and Alan Van Heuvelen, walks you through the innovative approaches they take to teaching physics. Each chapter of the *Instructor's Guide* contains a roadmap for assigning chapter content, *Active Learning Guide* assignments, homework, and videos of the experiments. In addition, the authors call out common pitfalls to mastering physics concepts and describe techniques that will help your students identify and overcome their misconceptions. Tips include how to manage the complex vocabulary of physics, when to use classroom response tools, and how to organize lab, lecture, and small-group learning time. Drawing from their extensive experience as teachers and researchers, the authors give you the support you need to make *College Physics* work for you.

The **Active Learning Guide** workbook (ISBN 0-134-60549-7) by Eugenia Etkina, David Brookes, Gorazd Planinsic, and Alan Van Heuvelen consists of carefully crafted cycles of in-class activities that provide an opportunity for students to conduct observational experiments, find patterns, develop explanations, and conduct the testing experiments for those explanations described in the textbook before they read it. These learning cycles are interspersed with "pivotal" activities that serve different purposes: (a) to introduce and familiarize students with new representational techniques, (b) to give students practice with representational techniques, (c) to directly address ideas that we *know* students struggle with (the goal is to encourage that struggle so that students reach a resolution either through their own discussion or by the instructor giving a "time for telling" lecture at the end of the activity), and (d) to provide scaffolding for students to work through an example or a passage in the textbook. The ALG also contains multiple experiments that can be used in labs. Whether the activities are assigned or not, students can always use this workbook to reinforce the concepts they have read about in the text, to practice applying the concepts to real-world scenarios, or to work with sketches, diagrams, and graphs that help them visualize the physics. The ALG is downloadable to share with your class; you may also talk to your sales representative about printing a custom version for your students.

The **Instructor Resource Materials** (ISBN 0-134-87386-6) on the Mastering Physics Instructor Resources page provide invaluable and easy-to-use resources for your class, organized by textbook chapter. The contents include a comprehensive library of all figures, photos, tables, and summaries from the textbook in JPEG and PowerPoint formats. A set of editable **Lecture Outlines**, **Open-Ended Questions**, and **Classroom Response System "Clicker" Questions** in PowerPoint will engage your students in class. Also included among the Instructor Resource Materials are the **Test Bank**, **Instructor Solutions Manual**, **Active Learning Guide**, **Active Learning Guide Solutions Manual**, and **Instructor Guide**.

Mastering™ Physics is the leading online homework, tutorial, and assessment platform designed to improve results by engaging students with powerful content. All Mastering resources, content, and tools are easy for both students and instructors to access in one convenient location. Instructors ensure that students arrive ready to learn by assigning educationally effective content before class and encourage critical thinking and retention with in-class resources such as Learning Catalytics™. Students can master concepts after class through traditional and adaptive homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments in one place, while diagnostic tools give instructors access to rich data to assess student understanding and misconceptions.

New for the second edition of this book, Mastering Physics includes activities for students to do before coming to class, as an alternative to working through the *Active Learning Guide* activities prior to reading the textbook. These activities focus students' attention on observational experiments, helping them learn to identify patterns in the data, and on testing experiments, helping them learn how to make a prediction of an outcome of an experiment using an idea being tested, not personal intuition. Both skills are very important in science, but are very difficult to develop.

The significantly revised **Instructor's Solutions Manual**, provided as PDFs and editable Word files, gives complete solutions to all end-of chapter questions and problems using the textbook's problem-solving strategy.

The **Test Bank**, which has also been significantly revised, contains more than 2000 high-quality problems, with a range of multiple-choice, true/false, short-answer, and regular homework-type questions. Test files are provided in TestGen® (an easy-to-use, fully networkable program for creating and editing quizzes and exams), as well as PDF and Word format.

Student supplements

Physics experiment videos, accessed via the eText, with a smartphone through this QR code, at https://goo.gl/s2MerO, or online in the Mastering Physics Study Area, accompany most of the Observational and Testing Experiment Tables, as well as other discussions and problems in the textbook and in the ALG. Students can observe the exact experiment described in the text.

VIDEO

The **Pearson eText,** optimized for mobile, seamlessly integrates videos and other rich media with the text and gives students access to their textbook anytime, anywhere.

- The Pearson eText mobile app offers offline access and can be downloaded for most iOS and Android phones/tablets from the Apple App Store or Google Play
- Accessible (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode
- Instructor and student note-taking, highlighting, bookmarking, and search

The **Student Solutions Manual** (ISBN 0-134-88014-5) gives complete solutions to select odd-numbered end-of-chapter questions and problems using the textbook's problem-solving strategy.

In addition to content assigned by the instructor and this text's accompanying experiment videos, **Mastering™ Physics** also provides a wealth of self-study resources:

- **Dynamic Study Modules** assess student performance and activity in real time. They use data and analytics that personalize content to target each student's particular strengths and weaknesses. DSMs can be accessed from any computer, tablet, or smart phone.
- **PhET simulations** from the University of Colorado, Boulder are provided in the Mastering Physics Study Area to allow students to explore key concepts by interacting with these research-based simulations.
- **24/7 access to online tutors*** enables students to work one-on-one, in real time, with a tutor using an interactive whiteboard. Tutors will guide them through solving their problems using a problem-solving-based teaching style to help them learn underlying concepts. In this way, students will be better prepared to handle future assignments on their own.

Acknowledgments

We wish to thank the many people who helped us create this textbook and its supporting materials. First and foremost, we want to thank our team at Pearson Higher Education, especially Jeanne Zalesky, who believed that the book deserved a second edition; Alice Houston, who provided careful, constructive, creative, enriching, and always positive feedback on every aspect of the book and the ALG; Darien Estes, who fearlessly made pivotal decisions that made the new edition much better; Susan McNally, who tirelessly shepherded the book through all stages of production; and David Hoogewerff, who oversaw the Mastering Physics component of the program. Tiffany Mok and Leslie Lee oversaw the new edition of the *Active Learning Guide* and other supplements. Special thanks to Jim Smith and Cathy Murphy who helped shape the first edition of the book. We also want to thank Adam Black for believing in the future of the project.

Although Michael Gentile is not a co-author on the second edition, this work would be impossible without him; he contributed a huge amount to the first edition and provided continuous support for us when we were working on the second edition. No words will describe how grateful we are to have Paul Bunson on our team. Paul helped us with the end-of-chapter problem revisions and Mastering Physics and ALG activities, and provided many helpful suggestions, particularly on rotational mechanics, fluids, relativity, and quantum optics. In addition, he was the first to adopt the textbook even before the first edition was officially printed and since then has remained a vivid advocate and supporter of ISLE. We are indebted to Charlie Hibbard, who checked and rechecked every fact and calculation in the text. Brett Kraabel prepared detailed solutions for every end-of-chapter problem for the *Instructor's Solutions Manual*. We also want to thank all of the reviewers, in particular Jeremy Hohertz, who put their time and energy to providing thoughtful, constructive, and supportive feedback. We thank Matt Blackman for adding excellent problems to the Test Bank, Katerina Visnjic for her support of ISLE and the idea to expand energy bar charts to nuclear physics, and Mikhail Kagan for timely feedback. Our special thanks go to Lane Seeley for his thoughtful review of the energy chapter, which led to its deep revision. We thank Diane Jammula and Jay Pravin Kumar, who not only became avid supporters and users of ISLE but also helped create instructor resources for the second edition. We thank Ales Mohoric and Sergej Faletic for their suggestions on problems.

Our infinite thanks go to Xueli Zou, the first adopter of ISLE, and to Suzanne Brahmia, who came up with the Investigative Science Learning Environment acronym "ISLE" and was and is an effective user and tireless advocate of the ISLE learning strategy. Suzanne's ideas about relating physics and mathematics are reflected in many sections of the book. We are indebted to David Brookes, another tireless ISLE developer, whose research shaped the language we use. We thank all of Eugenia's students who are now physics teachers for providing feedback and ideas and using the book with their students.

We have been very lucky to belong to the physics teaching community. Ideas of many people in the field contributed to our understanding of how people learn physics and what approaches work best. These people include Arnold Arons, Fred Reif, Jill Larkin, Lillian McDermott, David Hestenes, Joe Redish, Stamatis Vokos, Jim Minstrell, David Maloney, Fred Goldberg, David Hammer, Andy Elby, Noah Finkelstein, David Meltzer, David Rosengrant, Anna Karelina, Sahana Murthy, Maria Ruibal-Villasenhor, Aaron Warren, Tom Okuma, Curt Hieggelke, and Paul D'Alessandris. We thank all of them and many others.

Personal notes from the authors

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—Eugenia Etkina, Gorazd Planinsic, and Alan Van Heuvelen

*Please note that tutoring is available in selected Mastering products, and in those products you are eligible for one tutoring session of up to 30 minutes duration with your course. Additional hours can be purchased at reasonable rates.

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Melodi Rodrigue
University of Nevada, Reno
Charles Rogers
Southwestern Oklahoma State University
David Rosengrant
Kennesaw State University
Alvin Rosenthal
Western Michigan University
Lawrence Rowan
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Roy Rubins
University of Texas at Arlington
Otto Sankey
Arizona State University
Rolf Schimmrigk
Indiana University, South Bend
Brian Schuft
North Carolina Agricultural and Technical State University
Sara Schultz
Montana State University, Moorhead
Bruce Schumm
University of California, Santa Cruz
David Schuster
Western Michigan State University
Lane Seeley
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Southwestern Illinois College
Douglas Sherman
San Jose State University
Chandralekha Singh
University of Pittsburgh
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Nickolas Solomey
Wichita State University
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John Wernegreen
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Brian Woodahl
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Nicholls State University
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Real-World Applications

Contents

1

Introducing Physics

In everyday life, a model of something (such as a model airplane or a model train) is usually a smaller, simpler, or idealized version of the original. An architect creates a model to show a building's essential elements and context. Physicists do something similar, but it might surprise you to hear that in physics, a marble is a very useful model of an airplane, a car, or the Moon. Read on and you will learn why.

- What are physics models?
- How is the word "law" used differently in physics than in the legal system?
- How do we solve physics problems such as determining the minimum runway length needed for an airplane?

WHETHER YOU'VE STUDIED ANY physics before or not, it's helpful to take a step back and consider what physics is about and how physicists think about things. You'll find that learning to analyze problems like a physicist will help you not only in this course, but also in others (and in life in general). This book is designed to help you do this, and this chapter will give you an overview of how to use this book to your best advantage.

FIGURE 1.1 Archaeologists applied principles from physics to determine that this skeleton of *Australopithecus afarensis*, nicknamed "Lucy," lived about 3.2 million years ago.

1.1 What is physics?

Physics is a fundamental experimental science encompassing subjects such as motion, waves, light, electricity, magnetism, atoms, and nuclei. Knowing physics allows you to understand many aspects of the world, from why bending over to lift a heavy load can injure your back to why Earth's climate is changing. Physics explains the very small—atoms and subatomic particles—and the very large—planets, galaxies, and black holes.

In each chapter of this textbook, we will apply our knowledge of physics to other fields of science and technology such as biology, medicine, geology, astronomy, architecture, engineering, agriculture, and anthropology. For instance, you will learn about techniques used by archeologists to determine the age of bones (**Figure 1.1**), about electron microscopes and airport metal detectors, and why high blood pressure indicates problems with the circulatory system.

In this book we will concentrate not only on developing an understanding of the important basic laws of physics but also on the processes that physicists employ to discover and use these laws. The processes (among many) include:

- Collecting and analyzing experimental data.
- Making explanations and experimentally testing them.
- Creating different representations (pictures, graphs, bar charts, etc.) of physical processes.
- Finding mathematical relations—mathematical models—between different variables.
- Testing those relations in new experiments.

The search for rules

Physicists search for general rules, or **laws**, that bring understanding to the chaotic behavior of our surroundings. In physics the word *law* means a causal mathematical relation between variables inferred from the data or through some reasoning process. Causal relations show how change in one quantity affects the change in another quantity, but they do not explain why such causation occurs. The laws, once discovered, often seem obvious, yet their discovery usually requires years of experimentation and theorizing. Despite being called "laws," they are temporary in the sense that new information often leads to their modification, revision, and, in some cases, abandonment.

For example, in 200 B.C. Apollonius of Perga watched the Sun and the stars moving in arcs across the sky and adopted the concept that Earth occupied the center of a revolving universe. Three hundred years later, Ptolemy developed a detailed model to explain the complicated motion of the planets in that Earth-centered universe. Ptolemy's model, which predicted with surprising accuracy the changing positions of the planets, was accepted for the next 1400 years. However, as the quality of observations improved, discrepancies between the predictions of Ptolemy's model and the real positions of the planets became bigger and bigger. A new model was needed. Copernicus, who studied astronomy around the time that Columbus sailed to America, developed a model of motion for the heavenly bodies in which the Sun resided at the center of the universe while Earth and the other planets moved in orbits around it. More than 100 years later the model was revised by Johannes Kepler and later supported by careful experiments by Galileo Galilei. Finally, 50 years after Galileo's death, Isaac Newton formulated three simple laws of motion and the universal law of gravitation, which together provided a successful explanation for the orbital motion of Earth and the other planets. These laws also allowed us to predict the positions of new planets, which at the time were not yet known. Newton's work turned the heliocentric model into the theory of gravitation. For nearly 300 years Newtonian theory went unaltered until Albert Einstein made several profound improvements to our understanding of motion and gravitation at the beginning of the 20th century.

Newton's inspiration provided not only the basic resolution of the 1800-year-old problem of the motion of the planets but also a general framework for analyzing the mechanical properties of nature (**Figure 1.2**). Newton's simple laws give us the understanding needed to guide rockets to the Moon, to build skyscrapers, and to lift heavy objects safely without injury.

It is difficult to appreciate the great struggles our predecessors endured as they developed an understanding that now seems routine. Today, similar struggles occur in most branches of science, though the questions being investigated have changed. How does the brain work? What causes Earth's magnetism? What is the nature of the pulsating sources of X-ray radiation in our galaxy? Is the recently discovered accelerated expansion of the universe really caused by a mysterious "dark energy," or is our interpretation of the observations of distant supernovae that revealed the acceleration incomplete?

FIGURE 1.2 Thanks to Newton, we can explain the motion of the Moon. We can also build skyscrapers.

The processes for devising and using new models

Physics is an experimental science. To answer questions, physicists do not just think and dream in their offices but constantly engage in experimental investigations. Physicists use special measuring devices to observe phenomena (natural and planned), describe their observations (carefully record them using words, numbers, graphs, etc.), find repeating features called patterns (for example, the distance traveled by a falling object is directly proportional to the square of the time in flight), and then try to explain these patterns. By doing this, physicists describe and answer the questions of "why" or "how" the phenomena happened and then deduce quantitative rules called mathematical models that explain the phenomena.

However, a deduced explanation or a mathematical model is not automatically accepted as true. Every model needs to undergo careful testing. When physicists test a model, they use the model to predict the outcomes of new experiments. As long as there is no experiment whose outcome is inconsistent with predictions made using the model, it is not disproved. However, a new experiment could be devised tomorrow whose outcome is not consistent with the prediction made using the model. The point is that there is no way to "prove" a model once and for all. At best, the model just hasn't been disproven yet.

A simple example will help you understand some processes that physicists follow when they study the world. Imagine that you walk into the house of your acquaintance Bob and see 10 tennis rackets of different quality and sizes. This is an **observational experiment**. During an observational experiment a scientist collects data that seem important. Sometimes it is an accidental or unplanned experiment. The scientist has no prior expectation of the outcome. In this case the number of tennis rackets and their quality and sizes represent the data. Having so many tennis rackets seems unusual to you, so you try to explain the data you collected (or, in other words, to explain why Bob has so many rackets) by devising several hypotheses. A **hypothesis** is an explanation that usually is based on some mechanism that is behind what is going on, or it can be a mathematical model describing the phenomenon. One hypothesis is that Bob has lots of children and they all play tennis. A second hypothesis is that Bob makes his living by fixing tennis rackets. A third hypothesis is that he is a thief who steals tennis rackets.

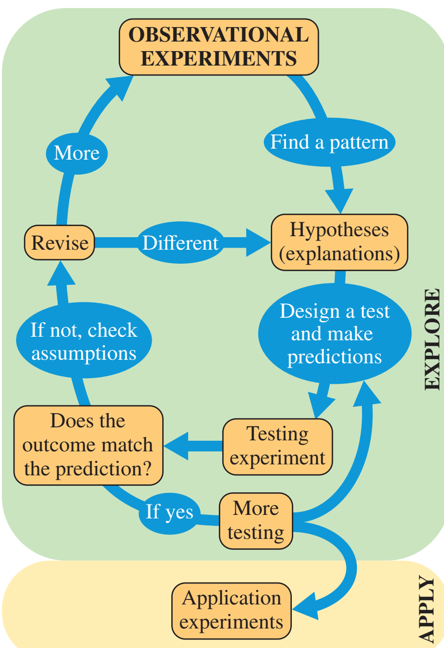
How do you decide which hypothesis is correct? You may reason: if Bob has many children who play tennis, and I walk around the house checking the sizes of clothes that I find, then I will find clothes of different sizes. Checking the clothing sizes is a new experiment, called a **testing experiment**. A testing experiment is different from an observational experiment. In a testing experiment, a specific hypothesis is being "put on trial." This hypothesis is used to construct a clear expectation of the outcome of the experiment. This clear expectation (based on the hypothesis being tested) is called a **prediction**. So you conduct the testing experiment by walking around the house checking the closets. You do find clothes of different sizes. This is the **outcome** of your testing experiment. Does it mean for absolute certain that Bob has the rackets

TIP Notice the difference between a hypothesis and a prediction. A *hypothesis* is an idea that explains why or how something that you observe happens. A *prediction* is a statement of what should happen in a particular experiment if the hypothesis being tested were true. The prediction is based on the hypothesis and cannot be made without a specific experiment in mind.

because all of his children play tennis? No; he could still be a racket repairman or a thief. Therefore, if the outcome of the testing experiment matches the prediction based on your hypothesis, you cannot say that you proved the hypothesis. All you can say is that you failed to disprove it. However, if you walk around the house and do not find any children's clothes, you can say with more confidence that the number of rackets in the house is not due to Bob having lots of children who play tennis. Still, this conclusion would only be valid if you made an **assumption**: Bob's children live in the house and wear clothes of different sizes. Generally, in order to reject a hypothesis you need to check the additional assumptions you made and determine if they are reasonable.

Imagine you have rejected the first hypothesis (you didn't find any children's clothes). Next you wish to test the hypothesis that Bob is a thief. This is your reasoning: *If* Bob is a thief (the hypothesis), *and* I walk around the house checking every drawer (the testing experiment), *then* I will not find any receipts for the tennis rackets (the prediction). You perform the experiment and you find no receipts. Does it mean that Bob is a thief? He might just be a disorganized father of many children or a busy repairman. However, if you find all of the receipts, you can say with more confidence that he is not a thief (but he could still be a repairman). Thus it is possible to disprove (rule out) a hypothesis, but it is not possible to prove it once and for all. The process that you went through to create and test your hypotheses is depicted in **Figure 1.3**. At the end of your investigation you might be left with a hypothesis that you failed to disprove. As a physicist you would now have some confidence in this hypothesis and start using it for practical applications.

FIGURE 1.3 Science is a cyclical process for creating and testing knowledge.



Using this textbook you will learn physics by following a process similar to that described above. The section "How to use this book to learn physics" at the end of this chapter will explain how to master this process.

Physicists use words and the language of mathematics to express ideas about the world. But they also represent these ideas and the world itself in other ways—sketches, diagrams, and even cut-out paper models (James Watson made a paper model of DNA when trying to determine its structure). In physics, however, the ultimate goal is to understand the mechanisms behind physical phenomena and to devise mathematical models that allow for quantitative predictions of new phenomena. Thus, a big part of physics is identifying measurable properties of the phenomena (such as mass, speed, and force), collecting quantitative data, finding the patterns in that data, and creating mathematical models representing relations between the quantities.

How will learning physics change your interactions with the world?

Even if you do not plan on becoming a professional physicist, learning physics can change the way you think about the world. For example, why do you feel cold when you wear wet clothes? Why is it safe to sit in a car during a lightning storm? Knowing physics will also help you understand what underlies many important technologies. How can a GPS know your present position and guide you to a distant location? How do power plants generate electric energy?

Studying physics is also a way to acquire the processes of knowledge construction, which will help you make decisions based on evidence rather than on personal opinions. When you hear an advertisement for a shampoo claim it will make your hair 97.5% stronger, you will ask: How do they know this? Did this number come from an experiment? If it did, was it tested? What assumptions did they make? Did they control for food consumed, exercise, air quality, etc.? Understanding physics will help you differentiate between actual evidence and unsubstantiated claims. For instance, before you accept a claim, you might ask about the data supporting the claim, what experiments were used to test the idea, and what assumptions were made. Thinking critically about the messages you hear will change the way you make decisions as a consumer and a citizen.

1.2 Modeling

You already met the word "model" in this chapter. In this section we will learn more about this term. Physicists study how the complex world works. To start the study of some aspect of that world, they often begin with a simplified version. Consider how you move your body when you walk. Your back foot on the pavement lifts and swings forward, only to stop for a short time when it again lands on the pavement, now ahead of you. Your arms swing back and forth. The trunk of your body moves forward steadily. Your head also moves forward but bobs up and down slightly. It would be very difficult to start our study of motion by analyzing all these complicated parts and movements. Thus, physicists create in their minds simplified representations, called **models**, of physical phenomena and then think of the phenomena in terms of those models. Physicists begin with very simple models and then add complexity as needed to investigate more detailed aspects of the phenomena.

FIGURE 1.4 Physicists often model complex structures as point-like objects.

We can ignore the chassis flexing and the driver moving and model this racecar as a point-like object in order to study its motion.

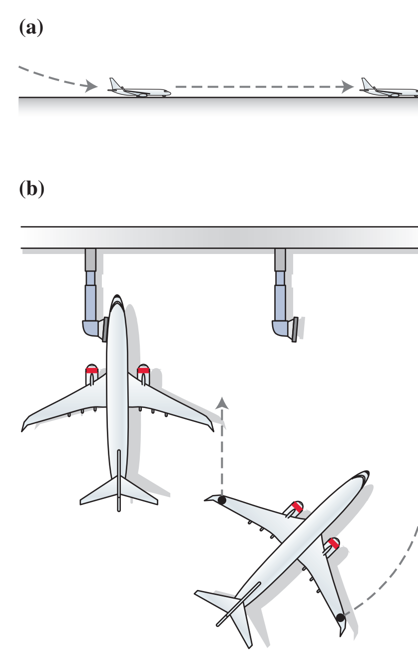
A simplified object

To simplify real objects, physicists often neglect both the dimensions of objects (their sizes) and their structures (the different parts) and instead regard them as single **point-like objects** (**Figure 1.4**).

Is modeling a real object as a point-like object a good idea? Imagine a 100-m race. The winner is the first person to get a body part across the finish line. The judge needs to observe the movement of all body parts (or a photo of the parts) across a very small distance near the finish line to determine who had the fastest time. Here, that very small distance near the finish line is small compared to the size of the human body. This is a situation where modeling the runners as point-like objects is not reasonable. However, if you are interested in how long it takes an average person to run 100 m, then the movement of different body parts is not as important, since 100 m is much larger than the size of a runner. In this case, the runners can be modeled as point-like objects. Even though we are talking about the same situation (a 100-m race), the aspect of the situation that interests us determines how we choose to model the runners.

Consider an airplane landing on a runway (**Figure 1.5a**). We want to determine how long it takes for it to stop. Since all of its parts move together, the part we study does not matter. In that case it is reasonable to model the airplane as a point-like object. However, if we want to build a series of gates for planes to unload passengers (Figure 1.5b), then we need to consider the motion of the different parts of the airplane. For example, there must be enough room for an airplane to turn while maneuvering into and out of the gate. In this case the airplane cannot be modeled as a point-like object.

FIGURE 1.5 An airplane can be considered a point-like object (a) when landing, but not (b) when parking.



Point-like object A point-like object is a simplified representation of a real object. As a rule of thumb, you can model a real object as a point-like object when one of the following two conditions is met: (a) when all of its parts move in the same way, or (b) when the object is much smaller than the other relevant lengths in the situation. The same object can be modeled as a point-like object in some situations but not in others.

Modeling

The process that we followed to decide when a real object could be considered a point-like object is an example of what is called **modeling**. The modeling of objects is the first step that physicists use when they study natural phenomena. In addition to simplifying the objects that they study, scientists simplify the interactions between objects and also the processes that are occurring in the real world. Then they add complexity as their understanding grows. Galileo Galilei is believed to be the first scientist to consciously model a phenomenon. In his studies of falling objects in the early 17th century, he chose to simplify the real phenomenon by ignoring the interactions of the falling objects with the air.

Modeling A model is a simplified representation of an object, a system (a group of objects), an interaction, or a process. A scientist creating the model decides which features to include and which to neglect.

As you see from above, there are different kinds of models. Those important for physics are mathematical models of processes. Models allow us to predict future phenomena.

1.3 Physical quantities

To describe physical phenomena quantitatively and model them mathematically, physicists construct **physical quantities**: features or characteristics of phenomena that can be determined experimentally, directly or indirectly. Determining the value of a physical quantity means comparing the characteristic to an assigned **unit** (a chosen standard).

TABLE 1.1 Power of 10 prefixes

Prefix	Abbreviation	Value
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}
Kilo	k	10^{3}
Hecto	h	10^{2}
Deka	da	10^{1}
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Femto	f	10^{-15}

Units of measure

Physicists describe physical quantities using the **SI system**, or *Le Système international d'unités*, whose origin goes back to the 1790s when King Louis XVI of France created a special commission to invent a new metric system of units. For example, in the SI system length is measured in meters. One meter is approximately the distance from your nose to the tip of the fingers of your outstretched arm. A long step is about one meter. Other units of length are related to the meter by powers of 10 using **prefixes** (milli, kilo, nano, …). These prefixes relate smaller or bigger versions of the same unit to the basic unit. For example, 1 millimeter is 0.001 meter; 1 kilometer is 1000 meters. The prefixes are used when a measured quantity is much smaller or much larger than the basic unit. If the distance is much larger than 1 m, you might want to use the kilometer (10^3 m) instead. The most common prefixes and the powers of 10 to which they correspond are given in Table 1.1. In addition to the unit of length, the SI system has six other basic units, summarized in Table 1.2.

TABLE 1.2 Basic SI physical quantities and their units

Physical quantity	Unit name and symbol	Physical description (approximate value)
Time	Second, s	One second is the time it takes for the heart to beat once.
Length	Meter, m	One meter is the length of one stride.
Mass	Kilogram, kg	One kilogram is the mass of 1 liter of water.
Electric current	Ampere, A	One ampere is the electric current through super bright white LEDs, such as those used in some street lamps.
Temperature	Kelvin, K	One kelvin degree is the same as 1 degree on the Celsius scale or about 2 degrees on the Fahrenheit scale. Half a kelvin (about 1 degree Fahrenheit) is the smallest temperature difference that the average person can detect by touching (with your hands).
Amount of matter	Mole, mol	One mole of anything contains 6×10^{23} of the units; one mole of oranges contains 6×10^{23} oranges.
Intensity of light	Candela, cd	One candela is the intensity of light produced by a relatively large candle at a distance of 1 m.

Table 1.2 provides a "feel" for some of the units but does not say exactly how each unit is defined. More careful definitions are important in order that measurements made by scientists in different parts of the world are consistent. However, to understand the precise definitions of these units, one needs to know more physics. We will learn how each unit is precisely defined when we investigate the concepts on which the definition is based.

Measuring instruments

Physicists use a measuring instrument to compare the quantity of interest with a standardized unit. Each measuring instrument is calibrated so that it reads in multiples of that unit. Some examples of measuring instruments are a thermometer to measure temperature (calibrated in degrees Celsius or degrees Fahrenheit), a watch to measure time intervals (calibrated in seconds), and a meter stick to measure the height of an object (calibrated in millimeters). We can now summarize these ideas about physical quantities and their units.

Physical quantity A physical quantity is a feature or characteristic of a physical phenomenon that can be measured in some unit. A measuring instrument is used to make a quantitative comparison of this characteristic with a unit of measure. Examples of physical quantities are your height, your body temperature, the speed of your car, and the temperature of air or water.

Significant digits

When we measure a physical quantity, the instrument we use and the circumstances under which we measure it determine how precisely we know the value of that quantity. Imagine that you wear a pedometer (a device that measures the number of steps that you take) and wish to determine the number of steps on average that you take per minute. You start walking at 3 p.m. according to your analog watch and stop when it shows 3:26, and see that the pedometer shows 2254 steps. You divide 2254 by 26 using your calculator, and it says 86.692307692307692. If you accept this number, it means that you know the number of steps per minute within plus or minus 0.000000000000001 steps/min. If you accept the number 86.69, it means that you know the number of steps to within 0.01 steps/min. If you accept the number 90, it means that you know the number of steps within 10 steps/min. Which answer should you use?

To answer this question, let's first focus on the measurements. Although it seems that you walked for 26 min, you could have walked for as few as 25 min or for as many as 27 min depending on whether you started a little after 3 p.m. or finished a little after 3:26. The number 26 does not give us enough information to know the time more precisely than that. The time measurement 26 min has two **significant digits**, or two numbers that carry meaning contributing to the precision of the result. The pedometer measurement 2254 has four significant digits. Should the result of dividing the number of steps by the amount of time you walked have two or four significant digits? If we accept four, it means that the number of steps per minute is known more precisely than the time measurement in minutes. This does not make sense. The number of significant digits in the final answer should be the same as the number of significant digits of the quantity used in the calculation that has the *smallest number of significant digits*. Thus, in our example, the average number of steps per minute should be 87. We rounded the result given by the calculator to two significant digits. This example shows that when we divide (or multiply) one term by another value, the number of significant digits in the result cannot be greater than the number of the significant digits in the term that has the fewest—in our case, two digits in the time. However, as we add or subtract values, the answer cannot have more decimal places than the term with fewest decimal places. For example, $30.517\text{ s} + 0.3\text{ s} = 30.8\text{ s}$.

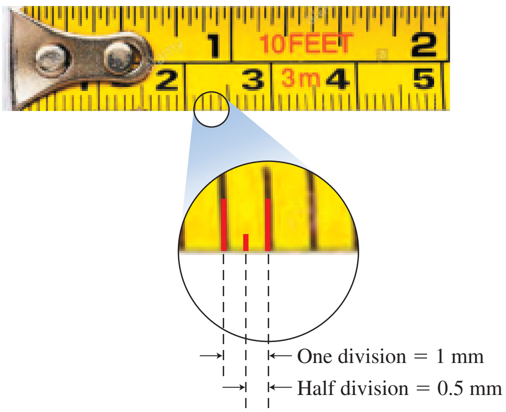


FIGURE 1.6 The precision of an instrument is determined by one-half of its smallest division. The smallest division of this measuring tape is 1 mm, so the precision is 0.5 mm.

Another issue with significant digits arises when a quantity is reported with no decimal points. For example, how many significant digits does 6500 have—two or four? This is where scientific notation helps. **Scientific notation** means writing numbers in terms of their power of 10. For example, we can write 6500 as 6.5×10^3. This means that the 6500 actually has two significant digits: 6 and 5. If we write 6500 as 6.50×10^3, it means 6500 has three significant digits: 6, 5, and 0. The number 6.50 is more precise than the number 6.5, because it means that you are confident in the number to the hundredths place. Scientific notation provides a compact way of writing large and small numbers and also allows us to indicate unambiguously the number of significant digits a quantity has.

Because we use instruments to measure quantities, we need to connect our knowledge of significant digits to the measurements. When we measure a quantity, we talk about precision. The **precision** of the value of a physical quantity is determined by one of two cases.

1. If the quantity is measured by a single instrument, its precision depends on the instrument used to measure it. **Figure 1.6** shows how the design of the measuring instrument determines its precision.
2. If the quantity is calculated from other measured quantities, then its precision depends on the least precise instrument out of all the instruments used to measure a quantity used in the calculation.

1.4 Making rough estimates

Sometimes it is useful to make a rough estimate of a physical quantity to help assess a situation or to make a decision. To do this, we use our personal knowledge or experience to get an approximate numerical value for an unknown quantity. Often the goal of the rough estimate is to determine the *order of magnitude* of the quantity—is it tens, hundreds, or thousands of the relevant units? Estimating is an extremely valuable skill not only in science but also in everyday life (**Figure 1.7**).

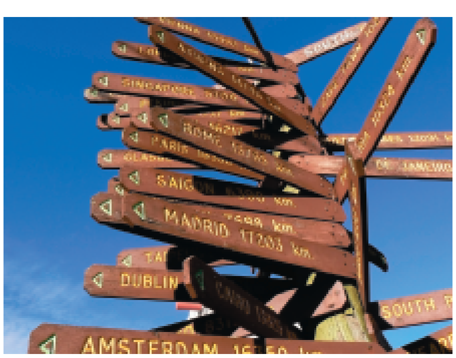


FIGURE 1.7 In everyday life, rough estimates are often sufficient.

For example, suppose we want to estimate the amount of drinking water that needs to be taken on a passenger airplane for a 4-h flight. We don't know exactly how many passengers are on the plane, but perhaps we assume that there are about 30 rows of seats with six seats per row. These data allow us to estimate the number of passengers: $30 \times 6 = 180$. After adding the crew and rounding the number, we can estimate the number of passengers to be 200. How many cups of water will each passenger drink? Some may drink six, but some only one. It seems reasonable to estimate that each person will drink about a cup of water every hour during the flight. Therefore, during a 4-h flight, 200 people will drink about 800 cups of water. How much water is in 1 cup? Again, if we don't know exactly, we can estimate it to be about 200 mL (a can of Coke holds about 350 mL). Our final estimation for the amount of water needed on the airplane is therefore 160,000 mL, or 160 L. You could argue that the airplane might be larger (with, say, 40 rows of eight seats) and that if the flight is during the daytime, people might drink more water (say six glasses per person). If you repeat the calculation using these new numbers, you will get about 380 L of water. This number is larger than our first estimate, but the order of magnitude is the same—hundreds of liters.

1.5 Vector and scalar quantities

There are two general types of physical quantities—those that contain information about magnitude as well as direction and those that contain magnitude information only. Physical quantities that do not contain information about direction are called **scalar quantities** and are written using *italic* symbols (m, T, etc.). Mass is a scalar quantity, as is temperature (**Figure 1.8**). To manipulate scalar quantities, you use standard arithmetic and algebra rules—you add, subtract, multiply, and divide scalars as though they were ordinary numbers.

Physical quantities that contain information about magnitude and direction are called **vector quantities** and are represented by italic symbols with an arrow on top ($\vec{F}$, $\vec{v}$, etc.). The little arrow on top of the symbol always points to the right. The actual direction of the vector quantity is shown in a diagram. For example, force is a physical quantity with both magnitude and direction (direction is very important if you are trying to hammer a nail into the wall). When you push a door, your push can be represented with a force arrow on a diagram; the stronger you push, the longer that arrow must be. The direction of the push is represented by the direction of that arrow (**Figure 1.9**). The arrow's direction indicates the direction of the vector, and the arrow's relative length indicates the vector's magnitude. The methods for manipulating vector quantities (adding and subtracting them as well as multiplying a vector quantity by a scalar quantity) will be introduced as needed in the following chapters.

FIGURE 1.8 Temperature is a scalar quantity; it has magnitude, but not direction. However, it can be positive or negative.

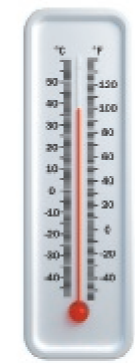
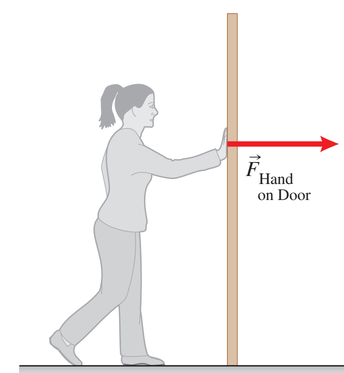


FIGURE 1.9 The force that your hand exerts on a door is a vector quantity represented by an arrow.



1.6 How to use this book to learn physics

The goals of this textbook are to help you construct understanding of some of the most important ideas in physics, learn to use physics knowledge to analyze physical phenomena, and develop the general process skills that scientists use in the practice of science. One such skill is learning from a scientific text. Thus, by learning to work with your textbook efficiently and productively, you will not only learn physics but also develop textbook reading skills that will be helpful in any other science subject you study. To take advantage of all the tools that this textbook has to offer, we suggest that you read the text below and then, after you work through the first few chapters, come back to this section and read it again.

The most important strategy that will help you learn better is called **interrogation**. Interrogation means continually asking yourself the same question when reading the text. This question is so important that we put it in the box below:

Why is this true?

Make sure that you ask yourself this question as often as possible so that eventually it becomes a habit. Out of all the strategies that are recommended for reading comprehension, this is the one that is directly connected to better learning outcomes. For example, in Section 1.2 you read the following sentence: "The modeling of objects is the first step that physicists use when they study natural phenomena." Ask yourself, "Why is this true?" Possibly because real-life phenomena are too complicated to be investigated in detail—it is much easier to describe the motion of a runner if you consider her to be a point-like object than to take into account the details of her arms, legs, hair, etc. Thus, simplifying, (or as physicists call it, modeling) is the first step that we take. By just stopping and interrogating yourself as often as possible about what is written in the book you will be able to understand and remember this information better.

Textbook features

This textbook has several features that repeat in every chapter. Recognizing these features and using them effectively not only will help you learn physics and shorten the time that you spend doing so, but also will help you develop good reading habits.